AN ANALYSIS OF TRAVEL
SPEED AND DELAY ON A
HIGH-VOLUME HIGHWAY

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by

T. B. TREADWAY

Joint
Highway
Research
Project

PURDUE UNIVERSITY
LAFAYETTE INDIANA

AN ANALYSIS OF TRAVEL SPEED AND DELAY

ON A HIGH-VOLUME HIGHWAY

To: K. B. Woods, Director
Joint Highway Research Project   July 9, 1965

From: H. L. Michael, Associate Director   Project: C-36-66C
Joint Highway Research Project   File: 8-7-3

The attached report, entitled "An Analysis of Travel Speed and Delay on a High-Volume Highway," is part of the Initial Inventory and Study for the project, Evaluation of the Effectiveness of Traffic Engineering Applied to the US 52 Bypass. This HPR-HPS research project, C-36-66C, was approved by the Advisory Board on March 6, 1964. The report was prepared by Mr. Theodore B. Treadway, Graduate Assistant, under the direction of Professor J. C. Oppenlander.

Relationships were developed to express overall travel speeds and delays as functions of elements that were descriptive of the traffic stream, roadway geometry, and roadside development. These equations permit the quantitative evaluation of traffic engineering improvements designed to reduce the travel time on the study bypass.

The report is presented for the record and will be submitted to the Highway Commission and the Bureau of Public Roads for review and comment.

Respectfully submitted,

Harold L. Michael

Harold L. Michael, Secretary

HLM:bc

Attachment

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Final Report

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ON A HIGH-VOLUME HIGHWAY

by

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Joint Highway Research Project

Project: C-36-66C

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ABSTRACT

Treadway, Theodore Barr. MSCE, Purdue University,
June 1965. <u>An Analysis of Travel Speed and Delay on a
High-Volume Highway</u>. Major Professor: J. C. Oppenlander.

This investigation was a part of a project designed
to evaluate the effectiveness of traffic engineering
applied to problems of traffic movement on the U.S. 52
Bypass in Lafayette, Indiana. The specific purposes of
this research were to identify the locations of delays on
the bypass, to determine the significant factors causing
these delays, and to make recommendations for improving
the flow of traffic.

The movements of traffic on the highway were classified
as uninterrupted flow between intersections and as interrupted
flow at the signalized intersections. Factor analysis and
multiple linear regression techniques were applied to
express overall travel speeds and delays as functions of
factors and variables that were descriptive of the traffic
stream, roadway geometry, and roadside development.

The most significant factors in accounting for the
variations in travel speeds of uninterrupted flow were the
types of roadside development (commercial, urban, and

rural) and stream friction. Vehicular delays at traffic
signals were largely dependent on the signal design, volume,
and the chance of whether or not stops occurred. These
results formed the basis of suggestions for reducing delays
on the bypass. Proposed short-range improvements included
the limitation and channelization of access points, the
improvement of the geometric design of signalized inter-
sections, and the critical evaluation of the signal-cycle
phases. A long-range recommendation was the reconstruc-
tion of the bypass as a four-lane, divided highway to
provide the proper highway and intersection capacities.

INTRODUCTION

The movement of people and goods is largely dependent on the motor vehicle. To insure the safe and efficient operation of motor vehicles at levels of comfort and convenience acceptable to the driver, an adquate system of highways is essential.

In recent years, vehicular travel has increased at a tremendous rate. The construction of new highways and the improvement of existing facilities have failed to keep pace with the growth of motor-vehicle travel. The problem is especially acute in urban areas, where major arterial highways lack needed capacity for handling the large movements of intracity travel. Many urban roads were constructed decades ago, when the present status of vehicular travel was inconceivable. Inadequate planning and improvement of these facilities have resulted in congestion and delays which are costly and irritable to the road users.

Limited-access freeways are being constructed in large urban areas to accommodate the major flows of through and intracity travel. Existing arterial highways continue to play an important role in the movement of traffic, however,

and they serve as collectors and distributors for the new
expressways. Through sound traffic engineering techniques,
the improvement of these arterial facilities is necessary
for the efficient and safe functioning of the complete trans-
portation system of an urban area. With a large expenditure
of funds for the construction of new roads, the continuing
renovation of the present highways has been largely
neglected.

A project was undertaken by the Joint Highway Research
Project of Purdue University, the Indiana State Highway
Commission, and the U. S. Bureau of Public Roads to evaluate
the effectiveness of traffic engineering as applied to the
improvement of a congested urban arterial highway. The
purpose of this research investigation, as a portion of
that project, was a detailed analysis of travel speeds and
delays on the highway. The specific objectives of this study
were the following:

1. Identify the locations of reduced travel
   speeds and delays;

2. Determine the significant factors and
   variables which influence travel speeds and
   delays;

3. Develop statistical models using these
   significant variables to predict travel
   speeds and delays; and

4. Make recommendations of traffic engineering
    techniques to improve the movement of
    traffic on this bypass facility.

The various mathematical models developed to express
travel speeds and delays as functions of factors and
variables that are descriptive of the roadway and its
environment gave an insight into the characteristics of
traffic flow on this study route. The relationships permitted
the determination and evaluation of appropriate improve-
ments in the existing roadway and in traffic control
devices to minimize travel delays. The planning and design
of new facilities are also benefited by the multivariate
analyses of travel speeds on existing highways.

REVIEW OF LITERATURE

The subjects of travel time, overall travel speed, and delay appear frequently in highway and traffic engineering literature. This literature review is confined to those articles which apply to this research investigation. The following topics are discussed.

1. Travel times, travel speeds, and delays

    a. Fundamental concepts

    b. Methods of field measurement

    c. Variables influencing travel speeds and delays

2. Multivariate analysis techniques

    a. Factor analysis

    b. Multiple linear regression and correlation analysis

Travel Times, Travel Speeds, and Delays

Travel time studies have been performed for various purposes, all of which are related to the evaluation of the level of service afforded by a highway section. Because the driver often considers total travel time in reaching his

destination as the criterion for selecting a certain route, travel time is given consideration in the evaluation of a highway system. (7)*

Some specific objectives of travel time studies are:

1. Identifying locations and causes of traffic delays,

2. Predicting traffic diversion from an existing roadway to a new facility, and

3. Analyzing road-user benefits. (6)

Fundamental Concepts

Overall travel time, composed of running time and stopped time, is the total interval during which a vehicle traverses a given section of highway. In most cases travel times are converted to rates of motion or overall travel speeds. Therefore, test sections of unequal lengths may be compared on a standard basis. (24)

The subject of delay is complicated by many different concepts. One definition is to consider delay as the stopped time. Another expression of delay is the difference between overall travel time and some "ideal" travel time, in which a driver can make a trip without stopping or slowing down for any reason. This level of travel time is difficult to measure quantitatively because of the variations among individual driving habits.

Various ratings and indices have been established to express delays. These ratings combine travel times and

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* Numbers in parentheses refer to items in the Bibliography.

speeds with volumes and fluctuations in speeds. Their use
is mostly limited to peak conditions. (4)

C. A. Rothrock and L. E. Keefer have proposed the
vehicle time-of-occupancy to indicate delay. This measure
is defined as the number of vehicles traveling through a
highway section in a given interval multiplied by the
average vehicular travel time. When too many vehicles occu-
py space for too long a time, congestion results. In field
studies the total vehicle time-of-occupancy increased
directly with volume for freeflowing conditions. As conges-
tion developed the vehicle time continued to increase while
volumes remained constant or decreased slightly. (23)

Methods of Field Measurement

Several methods have been used to measure travel times
and delays. Each technique has its own advantages and short-
comings, and the selection of the appropriate method depends
on the nature and the objectives of the study.

Travel Times. A reliable way of measuring travel times
is the license matching procedure, which often serves as a
standard for evaluating other methods. Observers record
the license numbers of vehicles and the times at which they
enter and leave a test section. The difference of the
values for a particular license number is the travel time
for that vehicle. This technique produces the true travel

times of vehicles traversing the test section, because the variations in individual driving habits are accounted for. Only total travel times are measured, however, and stopped times and running times, along with the locations and causes of delays are not obtained. The procedure is also time consuming as license numbers must be matched and travel times computed. (28)

A variation of the license matching process is the arrival-output method, in which only the times are recorded for vehicles entering and leaving the test section. The average travel time for the route is the difference of the average vehicle entrance time and the average vehicle exit time. This technique is applicable where all vehicles pass through the entire test section; that is, there are no points of access or egress along the roadway. (28)

The test-car procedure is most often used in obtaining travel-time data. The travel time of a test car driven in traffic stream is measured between selected control points. There are three variations of the test-car technique. One is the floating-car method, in which the driver is instructed to pass the same number of vehicles that overtake him. This procedure is most reliable for two-lane highways during low volumes and over long distances. (1, 6)

Greater accuracy has been obtained using the average-car technique. The driver is instructed to operate at a speed, which in his opinion, is representative of the speed

of all traffic in the stream. The balance in the number of passings is mentally noted, but the driver does not try to pass a vehicle every time another vehicle passes him. (3) D. S. Berry compared results from these two test-car methods to the license matching procedure and expressed the following conclusion:

> Average test cars, driven at speeds which, in the opinion of the drivers, are representative of the average speed of all traffic, can provide a practical measure of the mean travel time and the mean over-all travel speed of vehicles in the traffic stream of heavily traveled signalized urban streets and heavily traveled two-lane rural highways. (1)

Researchers at North Carolina State College disclosed that the average-car data estimated the true average speed within $\pm$ 2 mph, for a 5 percent level of significance. The true speed was calculated by the license matching method. (6)

The third variation is the maximum-car method. The test car is driven at the posted speed limit unless there is a restriction in the traffic stream. The advantage of this technique is that the variations in speeds due to psychological factors are minimized. Also, reductions in speeds and delays are caused by actual physical conditions and by restrictions in the traffic stream. (6) Consequently, an effective evaluation of the influence of roadway and traffic characteristics on delay is obtained. The procedure, does not produce an accurate indication of the average travel time.

Travel times are usually measured with a stop watch by an observer in the test vehicle. If supplementary data is desired, special types of measuring equipment are available. A speed and delay meter consisting of a printing and timing mechanism eliminates the need for an observer. The driver pushes a button which records the time, distance, and code number. This code identifies control points or causes and locations of delays. (17)

A continuous record of the test-car speed is produced by the recording speedometer. The movement of the paper on which the speed is recorded is either synchronized with the time or with the distance traveled by the vehicle. An alternate mechanism, the traffic chronograph, moves the paper in relation to the speed of the vehicle. The movement of the pen across the paper varies with time. (8) The uniqueness of these devices is that an actual picture of the speed fluctuations of the test car is recorded.

A special type of motion picture camera, the Markel Camera, has been used in test cars. Pictures taken through the windshield include speedometer and stop watch readings transmitted through a prism. (17)

The chief advantage of the test-car methods is that locations and causes of delay are readily identified. (28) In addition, test-car techniques facilitate the measuring of travel times for short segments of the highway. (3) The major disadvantage of the test car is that unreliable results

are obtained for low volume conditions or on multilane high-ways because the overall speed of the car is more directly a function of the driver's individual behavior.

Other manners of obtaining travel times are appropriate for certain conditions. Fixed-time interval photographs provide useful information on vehicle spacings, lane usage, merging and crossing maneuvers, queue formations, and their relationships to travel time. When this technique is applied, locations where the entire test section can be covered in the field of the camera must be available. In some instances special flying equipment has been utilized. (28) If time is limited and a large area is to be covered, field interviews are an advantageous way of obtaining travel-time data. (28) These interviews are used effectively with an origin and destination survey.

Investigations have been made with spot speeds as indications of overall travel speeds. The use of spot speeds in this manner assumes that the driver maintains his speed throughout the test section. Constant speeds are restricted to low-volume, free-flowing conditions. (1, 28)

Delays at Signalized Intersections. A major portion of the total vehicular delay on urban arterial highways occurs at signalized intersections. According to W. W. Johnston, three stops per mile reduce the capacity of a roadway by 50 percent. (18) Certain studies have been restricted to

measuring delays at traffic signals, and special methods for measuring these delays have been devised.

A sampling technique effectively estimates the total vehicle-seconds of stopped time at an approach to a signalized intersection. At specific intervals an observer records the number of vehicles stopped at that particular time. The total stopped time is computed by multiplying the total number of stopped vehicles by the interval of time between observations. When this procedure is used, the time interval between observations must not be some multiple of the signal cycle length. This requirement provides a sampling of different parts of the signal phase. (2)

A special type of delay meter accumulates the total vehicle-seconds of delay. This time is proportional to the number of vehicles stopped at a given instant. The operator of the meter continually adjusts a dial as the accumulation of stopped vehicles varies. (12)

Stationary cameras are also used to study delay at intersections. Pictures taken at intervals of 0.5, 1, or 2 sec include several hundred feet of the intersection approach. Stopped times, overall travel times, and volumes are obtained by examining the film on a screen with properly established grid lines. (2) Using the camera as a control, D. S. Berry found that both the delay meter and the sampling procedure provided reasonably consistent values of accumulated stopped times under high traffic volumes. The visual

sampling method produced results within 6.4 percent of those obtained by the serial photographs. (2)

Variables Influencing Travel Speeds and Delays

Previous investigations have been performed to determine those variables that have significant effects on travel speed. These variables are generally classified in the categories of traffic stream, roadway geometry, roadway development, and traffic controls.

Overall travel speed appears to be related closely to traffic volume. W. P. Walker found that for a highway section on which all variables were controlled except volume, the average speed of traffic decreased with an increase in volume. In rural areas a straight-line relationship occurred between volume and average travel speed when the critical density of the highway was not exceeded. Beyond this density, speed continued to decrease but volume also decreased because of congestion. (28) In the Chicago area travel speeds were observed to decrease continually with increasing volumes without a break signifying critical density. Product-moment correlations between speed and volume were low for rural and urban streets. (15)

The characteristics of the traffic stream have important effects on travel speed, but this influence has not been conclusively substantiated by field investigations. (28)

The character of traffic includes such items as through
traffic, local traffic, driver residence, trip purpose, and
trip destination. In one study, the percentage of commercial
vehicles had a negligible influence on travel speed. (33)

Little information is available concerning the relation-
ship of overall travel speed with highway geometry. A linear
correlation of travel time with street width was made by
R. R. Coleman. The width alone did not affect travel time
significantly. (33)

Commercial development causes delays to vehicular move-
ments in various ways. Additional traffic is generated and
delays are incurred by vehicles entering and leaving the
traffic stream. Commercial establishments also distract the
driver and divert his attention from the road ahead. The
effects of various types of impedances on the average overall
speeds of test vehicles were studied in North Carolina. Many
of these impedances were related to commercial development.
These resistances included various types of turning movements,
slow-moving vehicles, marginal friction such as parked cars
and pedestrians, and vehicles passing in the opposing direc-
tion. The presence of slow-moving vehicles had the most
significant influence in reducing speeds. Left and right
turns from the direction of travel of the test car were also
important causes of speed reductions. The remaining imped-
ances examined in that study were both individually and
collectively insignificant. The maximum-car technique was

used in this research. Definite negative linear relationships
were found between the speeds of the maximum car and the
numbers of slow-moving and turning vehicles that were
encountered. (6)

Turning movements have been studied separately for
various categories of commercial establishments. Multiple
linear regression equations were developed for each group.
The total number of turns per day was the dependent variable,
and the independent variables were daily traffic volume and
daily dollar income. Multiple correlation coefficients indi-
cated a high degree of linear relationship among the
variables. (6)

Poor weather conditions reduce vehicular speeds, but
the amount of reduction actually depends on the type and
severity of the weather. (16) In one investigation wet
pavements on all surface types did not significantly lower
vehicular speeds. (25) Delays resulting from snow and ice
vary with the prevailing conditions.

Investigations have been made to evaluate and compare
the performance of different types of traffic signals and
their relationships to travel speeds and delays. W. N. Volk
reported that stopped-time delays to vehicles which were
required to stop were much greater at fixed-time signals than
for traffic-actuated signals and for two-way and four-way
stopped-controlled intersections. In the same study inter-
sections exhibiting similar relationships between delays
and volumes were grouped together. Simple linear regression

equations were developed to predict delay from volume with
an acceptable degree of reliability. In many cases, however,
there was a great variation in the physical characteristics
of each intersection. (27)

A straight-line relationship between mean travel time
and signal density was established for urban areas in Penn-
sylvania. Regression equations developed for various
volume-to-capacity ratios were reasonably precise for
uncongested conditions. (5) Travel times for test sections
with coordinated signals were compared with times for a
series of non-coordinated signals. The sections with
coordinated signals had reduced travel times, but the
difference was not statistically significant. (5)

Multivariate Analysis Techniques

Multivariate analyses have recently become practical
statistical procedures with the advent of high-speed digital
computers. Previously, the number of variables included in
such analyses had to be limited because of the multiplicity
of computations involved. Different techniques have been
programed for computers, and the selection of the proper
method depends on the purpose and the nature of the study.
(18)

Factor Analysis

Factor analysis, employed primarily by behavioral scientists, is just beginning to be utilized in other fields such as highway research. This procedure resolves a given number of variables into a smaller number of factors, which describe a certain phenomenon. (18) A particular factor is a concept which embodies a number of variables that have something in common. (29) The method is especially useful where many variables are to be analyzed, as a smaller number of factors is easier to comprehend. (26) The subject of factor analysis is treated fully in various textbooks. (10)

J. Versace performed a factor analysis on accident rates and 13 other variables describing two-lane, rural highways. These variables were reduced to four factors: capacity, traffic conflict, modern roads, and roadside structures. Traffic conflict was the most significant factor in explaining accident rates. (26)

J. C. Oppenlander included a factor analysis in his study of spot speeds on two-lane, rural highways. Driver, vehicle, roadway, traffic, and environmental characteristics were represented by 48 variables, which were resolved into 17 factors. These factors were then correlated with spot speeds. Those factors which were statistically significant were horizontal resistance, long-distance travel, marginal friction, vertical resistance, and obsolete pavement. (18)

R. H. Wortman performed a similar investigation of four-lane, rural highways, and the two factors described as stream friction and traffic-stream composition significantly explained the mean spot speeds. (29)

Multiple Linear Regression and Correlation Analysis

Multiple linear regression and correlation techniques involve the seeking of a functional relationship between two or more related variables. (21) Multiple linear regression analysis is concerned with obtaining the best linear relationship among these variables while correlation analysis measures the degree of this linear association. (21)

This type of analysis has been utilized in predicting delay from volume for a certain type of intersection, and in estimating turning movements from volume and sales receipts. (6, 27). L. E. Keefer developed multiple linear regression equations to predict average travel speeds for different types of highway facilities in the urban area of Chicago. The equations contained from two to seven independent variables which described volume, traffic composition, friction points, and traffic signals.(15)

J. C. Oppenlander evolved a multiple linear regression model to estimate spot speeds on two-lane, rural highways. With the aid of factor analysis, eight independent variables were selected for use in the following model:

1. $S = 39.34 + 0.0267X_1 + 0.1369X_2 - 0.8125X_3$

$- 0.1126X_4 + 0.0007X_5 + 0.6444X_6 - 0.5451X_7$

$- 0.0082X_8$

where S = mean spot speed, mph,

X_1 = out-of-state passenger cars, percent,

X_2 = truck combinations, percent,

X_3 = degree of curve, degree,

X_4 = signed gradient, percent,

X_5 = minimum sight distance, ft,

X_6 = lane width, ft,

X_7 = number of commerical establishments, no. per mile, and

X_8 = total traffic volume, vph. (18)

Computer routines have been programed which enable multiple linear regression models to be built up or torn down, so that variables which contribute little to the functional relation-ship are eliminated. Consequently the final model contains only those variables which are statistically significant with the dependent variable. R. H. Wortman used this type of analysis in his study of four-lane, rural highways. (29)

PROCEDURE

This portion of the report describes the procedure
which was employed in conducting the study. The design of
the study, the methods of data collection, and the analysis
of the data are discussed. The highway analyzed in this
investigation was the U. S. 52 Bypass at Lafayette, Indiana.
A variety of traffic functions served by this two-lane
facility include:

1. Through traffic between Indianapolis, Chicago, and
   intermediate points;

2. Terminal traffic from throughout Tippecanoe County
   to Lafayette, an industrial center and the county
   seat, and to Purdue University in adjoining West
   Lafayette; and

3. Local traffic to commercial and industrial
   establishments abutting the bypass.

Design of Study

The bypass was divided into 18 homogeneous study
sections by considering geometry, speed limit, roadside
development, and location of traffic signals. These
sections are shown in Figure 1. Signalized intersections

U: UNINTERRUPTED FLOW
I: INTERRUPTED FLOW
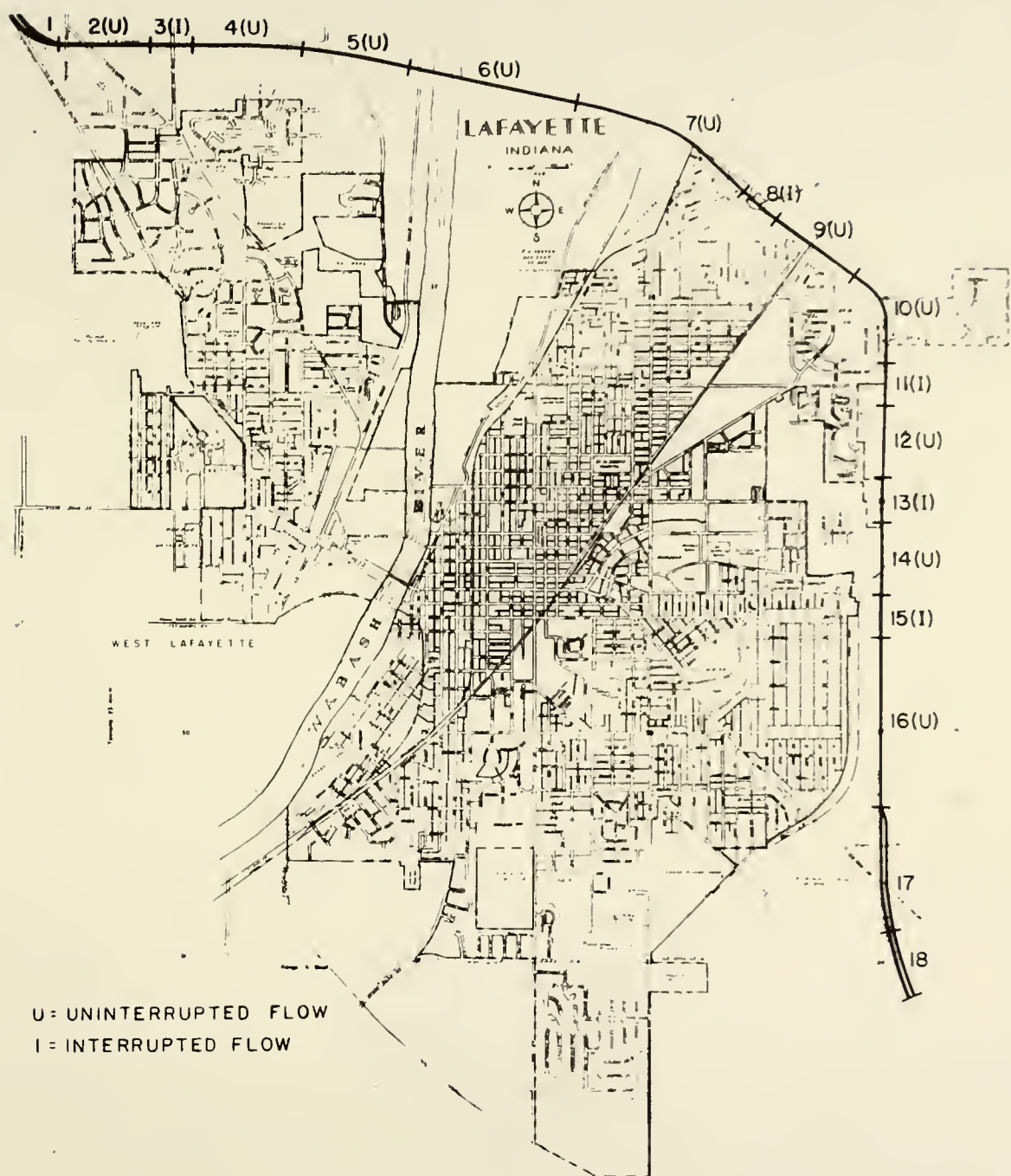
FIGURE I TEST SECTIONS OF
U.S. 52 BYPASS

were separated from the other sections of this route.
These intersections, which were categorized as "interrupted
flow," represented a special condition where traffic was
required to stop for the red-signal indication. A distance
of 500 ft on each side of the center of the intersection
was established to define the zone of influence of the
traffic signal. If the light changed and the driver was
required to stop, allowance was made for a reasonably
comfortable stop within this distance for uncongested condi-
tions. This distance was also sufficient for a vehicle
to resume a normal operating speed. Sections 3, 8, 11, 13,
and 15 were classified in this category of interrupted
flow. The signal in Section 3 was semi-actuated, and the
other four signals had fixed-time cycles. The remaining
portion of the two-lane bypass was designated and analyzed
as "uninterrupted flow." This category included Sections
2, 4, 5, 6, 7, 9, 10, 12, 14, and 16.

The remaining three unique sections of the bypass were
not included in the multivariate analyses of the interrupted
and the uninterrupted flows. Sections 1 and 17 included
transitions from a four-lane, divided highway to a two-
lane roadway; Section 18 was entirely a four-lane facility.
A required stop for all southbound traffic turning left
onto the bypass occurred in Section 1, and traffic signals
were present in Sections 17 and 18. Drawings of all sec-
tions are presented in Appendix A.

The selection of the variables to be included in the multivariate analyses was dependent on an examination of those variables included in previous investigations and on the availability and ease of collecting data. The following variables were included in the analysis of uninterrupted flow by direction of travel:

1 - Intersecting streets on the right - number per mile;

2 - Intersecting streets on the left - number per mile;

3 - Intersecting streets on both sides - number per mile;

4 - Access drives on the right - number per mile;

5 - Access drives on the left - number per mile;

6 - Access drives on both sides - number per mile;

7 - Commercial establishments on the right - number per mile;

8 - Commercial establishments on the left - number per mile;

9 - Commercial establishments on both sides - number per mile;

10 - Posted speed limit - mph;

11 - Average shoulder width on the right - ft;

12 - Average shoulder width on the left - ft;

13 - Portion of section length where passing was not permitted - percent;

14 - Average absolute grade - percent;

15 - Average algebraic grade - signed percent;

16 – Average curvature – deg;

17 – Geometric modulus (based on gradient, lane width, sight distance, and curvature); (8)

18 – Average safe stopping sight distance – ft;

19 – Practical capacity – vph;

20 – Possible capacity – vph;

21 – Advertising signs – number per mile;

22 – Warning signs – number per mile;

23 – Information signs – number per mile;

24 – Regulatory signs – number per mile;

25 – Presence of a truck climbing lane;

26 – Presence of a signal in the next section;

27 – Presence of a signal in the preceding section;

28 – Monday;

29 – Tuesday;

30 – Wednesday;

31 – Thursday;

32 – Friday;

33 – 8:00 a.m. to 10:00 a.m.;

34 – 10:01 a.m. to 12:00 m.;

35 – 12:01 p.m. to 3:00 p.m.;

36 – 3:01 p.m. to 6:00 p.m.;

37 – Traffic volume in direction of travel – vehicles per 15 min;

38 – Traffic volume in the opposing direction of travel – vehicles per 15 min;

39 - Commercial vehicles (larger than a small pickup
     truck) - percent;

40 - Southeast direction of travel;

41 - Northwest direction of travel;

42 - Total traffic volume - vehicles per 15 min;

43 - Volume to practical capacity ratio;

44 - Volume to possible capacity ratio; and

45 - Overall travel speed - mph.

The remaining variables were included in the analysis
of interrupted flow:

46 - Presence of a semi-actuated signal;

47 - Presence of a special signal for left-turn movement;

48 - Presence of a special right-turn lane;

49 - Length of approach to special turning lane - ft;

50 - Length of exit for special merging lane - ft;

51 - Average algebraic grade of approach - percent;

52 - Average algebraic grade of exit - percent;

53 - Intersecting streets, excluding that street with
     the signal, on the right - number;

54 - Intersecting streets, excluding that street with
     the signal, on the left - number;

55 - Intersecting streets, excluding those streets
     with the signal, on both sides - number;

56 - Access drives on the right - number;

57 - Access drives on the left - number;

58 - Access drives on both sides - number;

59 - Commercial establishments on the right - number;

60 - Commercial establishments on the left - number;

61 - Commercial establishments on both sides - number;

62 - Cycle length of traffic signal - sec per cycle;

63 - Green time in direction of flow - sec per cycle;

64 - Practical approach capacity - vph;

65 - Advertising signs - number;

66 - Warning signs - number;

67 - Information signs - number;

68 - Regulatory signs - number;

69 - Southeast direction of flow;

70 - Northwest direction of flow;

71 - Vehicles making left turns from the direction of
     travel - percent;

72 - Vehicles making right turns from the direction of
     travel - percent;

73 - Vehicles making left turns from the opposing
     direction of travel - percent;

74 - Average shoulder width on the right - ft;

75 - Average shoulder width on the left - ft;

76 - Monday;

77 - Tuesday;

78 - Wednesday;

79 - Thursday;

80 - Friday;

81 - 8:00 a.m. to 10:00 a.m.;

82 - 10:01 a.m. to 12:00 m.;

83 - 12:01 p.m. to 3:00 p.m.;

84 - 3:01 p.m. to 6:00 p.m.;

85 - Traffic volume approaching the intersection in the direction on travel - vehicles per 15 min;

86 - Traffic volume approaching the intersection in the opposing direction of travel - vehicles per 15 min;

87 - Total traffic volume entering the intersection on all four approaches - vehicles per 15 min;

88 - Commercial vehicles (larger than a small pickup truck) - percent;

89 - Green time to cycle length ratio;

90 - Approach volume to total volume entering intersection ratio;

91 - Approach volume to practical capacity ratio;

92 - Overall travel speed - mph; and

93 - Delay (total delay for the test vehicle traveling through the intersection) - sec.

Variables comprising street, access drive, and commercial densities were expressed in a "per mile" form for the uninterrupted flow sections because of the variation in section lengths. The lengths of the interrupted flow sections were uniform, and similar variables for this analysis were retained as an absolute value. Because all traffic lanes of the bypass were 11-ft wide, lane width was not included as a variable.

Collection of Data

Many variables in both analyses described the physical characteristics, and these values remained constant for each test section. The exceptions were those variables associated with volumes, commercial vehicles, time periods, days of the week, travel speeds, and delays.

An inventory of the physical characteristics for the bypass was made from construction plans and aerial photographs. In some cases, actual measurements were performed in the field. Section lengths measured by a fifth-wheel odometer were checked with the control points located on the construction plans.

Possible and practical capacities were computed in accordance with methods described in the Highway Capacity Manual. (11) A special procedure was devised for computing capacities of the signalized intersections. All of the intersections had turning lanes on the right side for both directions of travel. In only one case, however, was the turning lane designated for a specific movement. Drivers used the added lanes for making right turns and for passing vehicles waiting to make left-hand turns. The additional lane was not fully effective as a special turning lane in increasing the approach capacity.

Capacities were first computed for the through lane. In addition, the capacities of the added turning lane were

calculated for the following conditions:

1. If the predominant turning movement was to the right, the added lane was considered as a right-turn lane; or

2. If the predominant turning movement was to the left, the center lane was considered as a special left-turn lane, and the added lane on the right was assumed to handle through and right-turn movements.

Capacities were observed at a selected intersection by counting the number of vehicles passing through the traffic signal during loaded green cycles. In a loaded cycle there was always a vehicle waiting to enter the intersection. The observed capacities were approximately one-third of the computed capacities of the special turning lanes. Therefore, all capacities of the added turning lanes were considered as one-third of the amount calculated from the Highway Capacity Manual. (11)

Volumes were recorded simultaneously with the measurement of travel times. Counts were taken at four points for 15-min intervals. The control stations, located in Sections 2, 6, 10, and 16, were used to expand the volumes by hour and by direction for the remaining sections. All volumes were obtained with recording counters actuated by pneumatic hoses.

The result of a traffic composition analysis at representative sections was that the percentage of vehicles

larger than a small two-axle pickup truck was constant
for all sections of the bypass. Hourly fluctuations did
occur, and ratios were established for different periods
of the day. The percentages of vehicles turning right and
left at a given signalized intersection did not vary signifi-
cantly for different periods of the day. Average values for
all types of turning movements included in the analysis were
established for each intersection.

Travel times were measured by the average-car technique.
This method was especially appropriate, because the heavy
traffic volumes permitted few opportunities for passing
maneuvers. The driver operated the test car at a speed
which in his opinion was representative of the average speed
of the traffic stream. During periods when the test car
was not influenced by other vehicles, the driver observed
the speed limit. Travel times at the section boundaries
were recorded with a stop watch by an observer in the car.
Whenever the vehicle was forced to stop, the duration of
this stop was measured with a second stop watch.

Forty runs were made in each direction to assure a
good estimate of the mean travel speed for each section.
(1,19) This procedure provided a sample size of 800
observations for the ten sections representing uninterrupted
flow. Five sections provided a sample size of 400 observa-
tions for the analysis of interrupted flow.

All test car runs were made over the entire length of
the bypass. The test vehicle entered the traffic stream

about 0.5 mile before the first section and continued for
approximately the same distance after the last section.
The data collections were made on weekdays, in daylight
between the hours of 8:00 a.m. and 6:00 p.m., and during
clear and dry weather conditions. To insure a variation
in traffic volumes, trips were made during peak and off-peak
hours.

Analysis of Data

Data collected in this investigation were coded, punched
on IBM cards, and verified. The computations were performed
on an IBM 7094 Computer. In addition to using programs from
the Statistical Laboratory of Purdue University, special
programs were written to organize and summarize the data.

Preliminary Data Processing

The data were first processed and summarized before the
multivariate analyses were initiated. A flow diagram of the
procedure is depicted in Figure 2. Travel times for each
run and section were converted to overall travel speeds as
follows:

$$2. \quad S = \frac{L\ (3600)}{T}$$

where S = overall travel speed, mph,

     L = length of test section, miles, and

     T = travel time, sec.
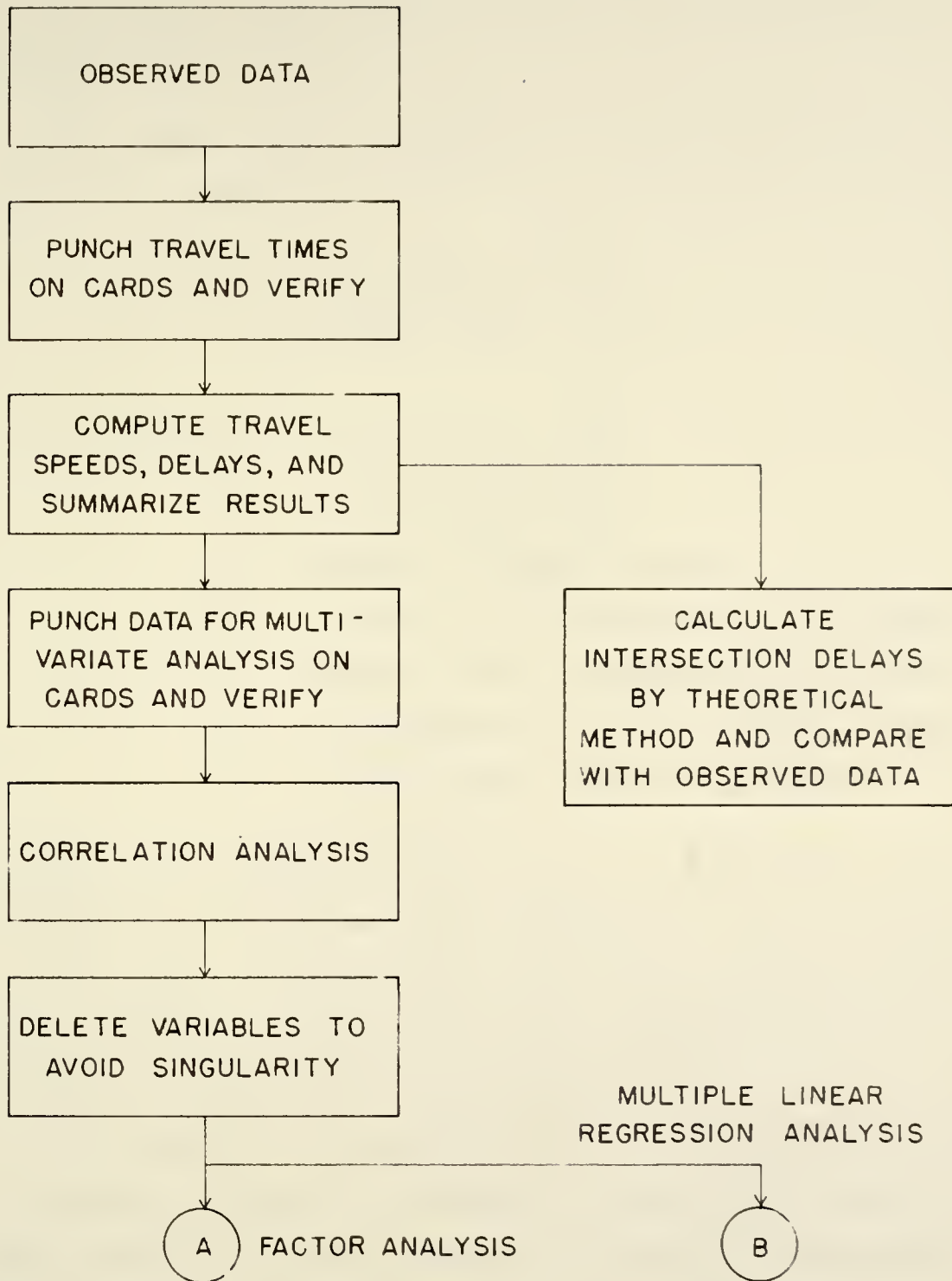
FIGURE 2   FLOW DIAGRAM FOR
            DATA PROCESSING

The mean travel speed and stop time for each section and direction were calculated.

The travel delay for each run at signalized intersections was computed as follows:

$$3. \quad D = T - \left[\frac{L \ (3600)}{0.5 \ (\bar{S}_B + \bar{S}_A)} \right]$$

where D = travel delay, sec,

T = travel time, sec,

L = length of section, miles,

$\bar{S}_B$ = average overall travel speed of adjacent section before intersection, mph, and

$\bar{S}_A$ = average overall travel speed of adjacent section after intersection, mph.

The term in the brackets in Equation 3 was considered as the hypothetical travel time if the intersection had not existed. In a few cases where the computed delay was a negative value, these delays were assumed to be zero. The delays were averaged for each intersection by direction.

The average delay per vehicle for each signalized intersection was again calculated by a theoretical method which depends on the red interval of the cycle, the average arrival headways in the traffic stream, and the starting performance of the queue.. The delay for any vehicle is:

4. $\quad d_i = R - \dfrac{A(2i - 1)}{2} + \displaystyle\sum_{x=1}^{i} D_x$

where $\quad d_i$ = delay for i-th vehicle, sec,

$\quad\quad\quad\quad R$ = length of stop time in cycle, sec,

$\quad\quad\quad\quad A$ = average arrival headway, sec,

$\quad\quad\quad\quad i$ = any selected vehicle, and

$\quad\quad\quad\quad D_x$ = headway of departure of x-th vehicle,

$\quad\quad\quad\quad\quad$ sec.

The total delay for the n vehicles stopped in R is:

5. $\quad T = nR - \dfrac{n^2 A}{2} + \displaystyle\sum_{x=1}^{n} \sum_{x=1}^{i} D_x$

where T = total delay for all vehicles, sec, and

$\quad\quad\quad n$ = total number of vehicles stopped in R.

The equation is simplified by considering D as a constant:

6. $\quad T = nR - \dfrac{n^2 A}{2} + \dfrac{2.1(n)(n + 1)}{2} + 3.7n - Q$

where $\quad D$ = constant (depending on the value on n).

The number of vehicles stopped in the red interval is
determined by differentiating T with respect to n:

7. $\quad n = \dfrac{R + 4.75}{A - 2.1}$

The average delay per vehicle is:

8. $\quad \bar{T} = \dfrac{TA}{C}$

where $\overline{T}$ = average delay per vehicle, sec, and

C = cycle length, sec.

Complete details of this derivation are presented in the textbook, Traffic Engineering. (16)

Multivariate Analyses

The first step in each multivariate analysis was the calculation of a correlation matrix for the study variables, because certain variables had to be deleted to avoid singularities. These variables included commerical establishments, access drives, street intersections, and volumes. If any two of the three variables (for example number of access drives on the right, number of access drives on the left, and total number of access drives) were known, then the third value could be computed. The variable which had the smallest product-moment correlation with the dependent variable was removed.

Factor Analysis. Before the factor analysis was performed, the dependent variables were deleted from the correlation matrix. This procedure permitted later correlations between the dependent variables and the generated factors. A flow diagram for the factor analysis is shown in Figure 3.
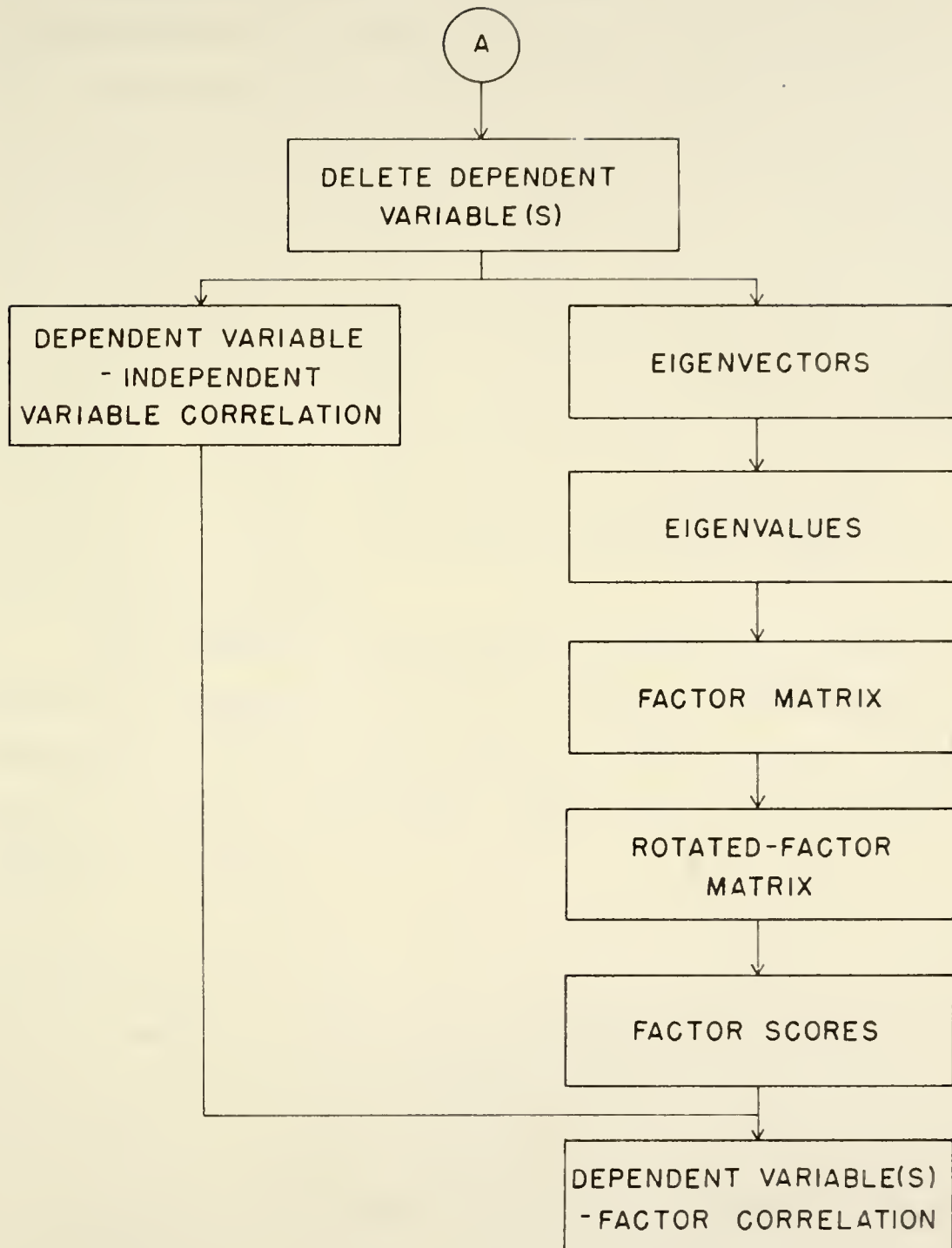
FIGURE 3   FLOW DIAGRAM FOR
FACTOR ANALYSIS

Orthogonal factors were generated so that a maximum contribution to the residual communality was provided.(20, 31)   The generation of the factors was terminated when the eigenvalue became less than 1.00. It has been arbitrarily established that factors with eigenvalues of 1.00 contribute significantly to the total variance of the variables. (18) The factor matrix was thus established, which contained less elements than the original correlation matrix. This factor matrix was rotated with the varimax method to aid interpretation of each factor. (20, 31) An examination of the rotated-factor matrix resulted in the identificiation of the generated factors.

Coefficients were developed to express each factor in terms of the original variables. Thus, the factors were evaluated from the values of the variables that were significantly related to each factor. These factor scores were computed as follows:

9. $E = FA'Y^{-2}A$

where E = factor-score matrix,

F = rotated-factor matrix,

A = factor matrix, and

Y = diagonal matrix of eigenvalues. (18)

The final step in the factor analysis was the correlation of the factors with the dependent variables. The resulting multiple linear regression equation expressed

the dependent variable as a function of the significant
factors. The regression coefficients were calculated from
the following matrix equation:

    10. $c = Er'$

       where c = column vector of regression coefficients,

            E = factor-score matrix, and

            r = row vector of correlation coefficients

                for dependent variables correlated with

                other variables. (18)

<u>Multiple Linear Regression and Correlation Analysis</u>. A
build up regression analysis was performed on the study
variables. (32) A flow diagram for this procedure is shown
in Figure 4. At each step in the routine, a "F-to-remove"
value was computed for each variable in the regression
equation, and "F-to-enter values" were computed for the
variables not in the equation. Independent variables were
deleted and added under the following conditions:

    1. If in the regresson equation there were one or
        more independent variables which had an F value
        less than the critical "F-to-remove" value speci-
        fied, the variable with the smallest F value was
        removed;

    2. If no variable was removed and there were one or
        more independent variables, not in the regression
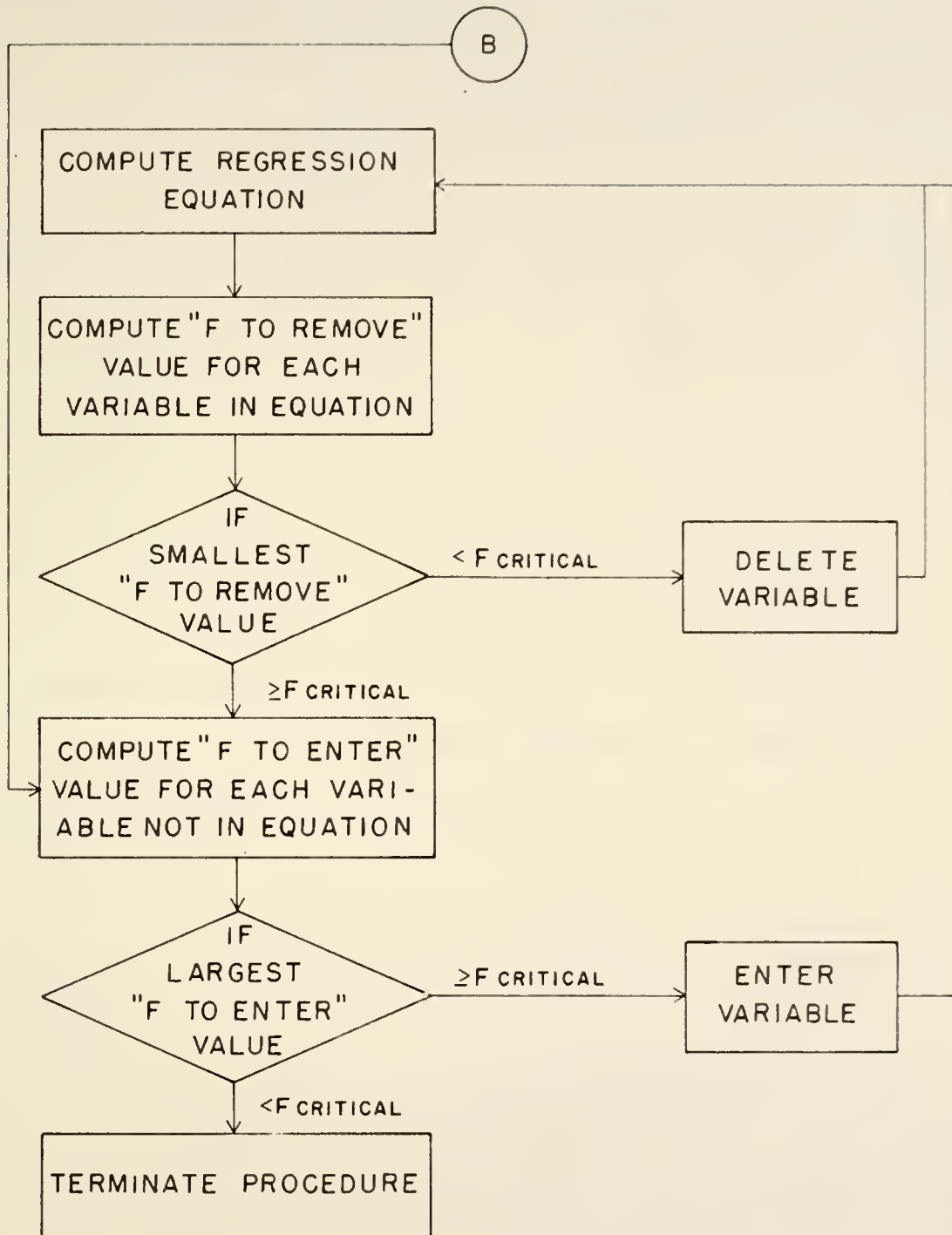
FIGURE 4   FLOW DIAGRAM FOR MULTIPLE LINEAR REGRESSION ANALYSIS

equation, which passed a tolerance test, the
variable with the highest F value was added; and

3. If no variable was added or deleted, the procedure
was terminated. (20)

Values of 0.01 and 0.005 were specified as F-levels for
inclusion and deletion, respectively. The variables were
assigned numerical ratings. Those variables with the lowest
rating were considered first for deletion; likewise, the vari-
ables with the highest rating were considered initially for
entrance into the equation. The procedure was repeated for
the variables with the next-to-lowest and next-to-highest
ratings considered for exit and entrance, respectively,
until the program was terminated. These ratings affected
only the order of adding and removing the study variables,
and the regression coefficients were not altered in magnitude
or sign. (20)

The following criteria were used in rating the vari-
ables for inclusion in the multiple linear regression equa-
tions:

1. Each significant factor was represented by at
least one closely related variable;

2. The final model involved a minimum of computations
with readily obtainable data; and

3. The multiple coefficient of determination did not
increase significantly by including additional
variables.

Mathematical Models

The development of functional relationships between the dependent variables and the factors and independent variables involved the formulation of mathematical models. These statistical models provide a basis of formulating theories in traffic flow. The types of multiple linear regression equations used in the analysis were:

11. $Y_1 = \bar{Y} + y (c_1 F_1 + c_2 F_2 + \ldots + c_q F_q)$

where Y_1 = predicted mean dependent variable,

$\bar{Y}$ = grand mean of dependent variable,

y = standard deviation of dependent variable,

c = common factor coefficient,

F = common factor, and

q = number of common factors.

12. $Y_2 = a + b_1 X_1 + b_2 X_2 + \ldots + b_p X_p$

where Y_2 = predicted mean dependent variable,

a = intercept,

b = regression coefficient,

X = independent variable, and

p = number of independent variables.

These multiple linear regression equations were developed assuming that the sample data were randomly selected from normal populations. Also, homogeneity of variance was assumed for the study variables.

RESULTS

The results of the multivariate analyses of travel speeds and delays are presented and discussed in this section. The data were first summarized by computing mean travel speeds and delays for each study section. A factor analysis was performed to gain an insight into the relationships among the study variables. Multiple linear regression equations were developed to predict mean travel speeds and delays in terms of the factors and the variables. The results of these analyses were then applied in recommending improvements to minimize delays on the bypass location. All variables were identified by the numbers which are listed in the discussion of the experimental design. Each factor was labeled with a letter in the evaluation of the results of the factor analysis.

Uninterrupted Flow

The overall travel speeds for each test section in the analysis of uninterrupted flow were averaged for both directional flows and the combined flows. These mean travel speeds are summarized in Table 1. The highest speeds occurred in Sections 5, 6, and 7 where the commerical roadside

TABLE 1

AVERAGE OVERALL TRAVEL SPEEDS, UNINTERRUPTED FLOW

Section	Average Overall Travel Speed, mph		
	SE Flow	NW Flow	Combined Flows
2	41.4	40.6	41.0
4	42.0	47.7	44.9
5	51.0	52.5	51.8
6	52.8	53.9	53.4
7	45.1	45.2	45.2
9	40.3	42.0	41.2
10	40.8	42.6	41.7
12	34.4	39.3	36.9
14	30.4	33.5	32.0
16	35.3	35.3	35.3

development was sparse. In Sections 12, 14, 16 where heavy commercial strip development occurred, the lowest speeds were recorded.

Factor Analysis

A correlation matrix was calculated for variables 1 to 45 inclusive. The correlation of travel speed with the other variables is presented in Table 14, Appendix B. Variables 2, 5, 8, and 38 were deleted from the matrix to avoid singularities. Variables 40 and 41, which identified the directional flows, and variable 45, overall travel speed, were also removed. This speed variable was later correlated with the generated factors. The revised correlation matrix was factorized with unities inserted in the main diagonal of the matrix. The 38 variables were reduced to 13 factors which accounted for 88 percent of the total variance of the variables. The eigenvalue and the portion of variation explained by each factor are shown in Table 15, Appendix B.

The 13 factors were then rotated to aid in their identification. This rotated-factor matrix is presented in Table 2. The signed factor coefficients indicate the relative importance of each variable in the explanation of the generated factors. The plus and minus signs are indicative, respectively, of the increasing or decreasing presence of the variables in the composition of the factors. Each factor

TABLE 2

ROTATED-FACTOR MATRIX, UNINTERRUPTED FLOW

Variable	Factors					
	A	B	C	D	E	F
1	-0.0056	+0.3019	+0.0138	+0.1050	+0.0222	+0.8397
3	-0.1582	+0.3942	-0.0119	+0.0404	-0.0071	+0.7510
4	+0.9290	-0.1625	+0.0069	-0.0207	-0.0020	+0.0790
6	+0.9294	-0.1848	+0.0079	-0.0088	+0.0006	-0.0676
7	+0.9176	-0.1792	+0.0054	-0.0354	-0.0062	+0.0188
9	+0.9287	-0.2071	+0.0079	-0.0119	-0.0021	-0.1201
10	-0.4930	-0.1115	-0.0062	+0.0555	+0.0011	-0.4368
11	+0.2341	+0.0806	+0.0101	+0.1530	-0.0035	+0.1327
12	+0.5259	+0.0973	+0.0108	-0.2712	-0.0112	+0.5798
13	-0.0929	+0.9244	-0.0273	-0.0062	-0.0115	+0.1711
14	-0.3658	+0.1278	+0.0171	-0.1663	+0.0404	-0.2513
15	+0.0152	+0.0130	-0.0093	-0.9151	-0.0134	+0.0981
16	-0.0560	+0.7644	-0.0101	-0.0366	+0.0009	+0.1718
17	+0.2464	-0.8693	+0.0228	+0.0199	+0.0175	-0.1567
18	+0.1329	-0.7443	+0.0312	-0.0305	+0.0457	-0.2903
19	+0.4734	-0.7638	+0.0404	-0.0406	+0.0224	+0.1154
20	-0.0910	-0.7556	+0.0412	-0.1030	+0.0424	-0.1330
21	+0.0862	+0.2952	+0.0013	+0.1395	+0.0143	+0.2244
22	+0.2828	+0.1170	+0.0064	-0.6533	+0.0102	-0.2374
23	-0.1591	+0.0204	-0.0179	-0.1585	-0.0260	-0.2668
24	+0.1862	-0.4398	+0.0198	-0.0983	+0.0126	+0.4697
25	-0.1380	-0.2072	+0.0134	-0.6860	+0.0231	-0.0665
26	+0.4114	+0.0460	+0.0034	-0.3607	-0.0081	-0.0014
27	+0.5888	+0.1605	-0.0065	+0.3658	-0.0169	+0.1828
28	-0.0042	+0.0108	+0.3523	+0.0026	+0.1313	-0.0053
29	+0.0066	+0.0096	+0.1059	+0.0106	+0.1712	+0.0031
30	-0.0028	-0.0181	-0.1230	-0.0092	-0.7612	+0.0114
31	+0.0054	-0.0139	-0.6170	-0.0078	+0.4544	-0.0045
32	-0.0066	+0.0221	+0.4392	+0.0079	+0.2336	-0.0104
33	+0.0035	-0.0228	-0.2464	-0.0187	+0.1671	-0.0021
34	+0.0033	-0.0111	-0.7637	+0.0030	+0.3788	+0.0152
35	-0.0029	-0.0044	-0.0831	+0.0041	-0.8616	-0.0145
36	-0.0025	+0.0252	+0.8724	+0.0042	+0.3225	+0.0007
37	+0.4374	+0.0378	+0.4516	-0.0408	+0.2133	+0.0624
39	+0.0110	-0.0231	-0.9082	-0.0102	-0.0649	+0.0034
42	+0.4683	+0.0246	+0.4839	-0.0671	+0.2212	+0.0691
43	-0.0865	+0.8605	+0.2957	-0.0169	+0.1362	-0.0730
44	+0.3728	+0.4906	+0.3996	-0.0408	+0.1786	+0.0933

TABLE 2 (continued)

ROTATED-FACTOR MATRIX, UNINTERRUPTED FLOW

Vari-able	Factors					
	G	H	I	J	K	L
1	+0.1597	+0.0250	+0.0975	-0.0037	+0.0773	+0.0394
3	+0.0653	-0.0046	+0.0619	+0.0028	-0.2194	-0.2498
4	+0.0935	-0.0008	+0.0507	+0.0006	+0.0953	+0.1060
6	+0.0927	+0.0084	+0.0331	-0.0002	-0.1987	+0.1314
7	-0.0165	-0.0078	+0.0085	+0.0028	+0.0608	+0.0951
9	+0.0811	+0.0035	+0.0391	+0.0006	-0.2030	+0.1204
10	+0.1946	-0.0186	+0.0579	+0.0025	+0.4167	-0.4439
11	-0.0568	+0.0053	+0.1403	+0.0004	-0.9113	+0.1382
12	-0.0889	-0.0233	+0.1173	+0.0055	-0.1279	+0.1007
13	+0.0368	-0.0069	+0.0034	+0.0030	+0.0506	+0.0731
14	-0.0000	+0.0415	-0.0422	-0.0091	+0.0471	-0.7621
15	+0.0099	-0.0272	-0.0690	+0.0044	+0.1590	+0.0121
16	+0.1062	-0.0021	+0.1479	+0.0013	-0.1802	-0.2101
17	-0.0650	+0.0217	+0.1955	-0.0051	+0.1725	+0.1838
18	-0.0324	+0.0582	+0.1338	-0.0132	+0.3621	-0.1321
19	-0.1195	+0.0359	-0.1455	-0.0079	-0.3058	+0.1091
20	-0.0495	+0.0459	-0.1917	-0.0105	-0.0444	-0.5213
21	+0.7895	+0.0170	-0.1126	-0.0027	+0.0827	-0.0915
22	+0.0229	+0.0215	-0.1459	-0.0031	-0.4894	-0.1205
23	+0.0568	-0.0234	-0.8789	+0.0033	+0.0959	-0.0811
24	+0.1050	+0.0251	-0.5969	-0.0052	-0.0132	+0.0728
25	-0.1440	+0.0173	-0.1473	-0.0048	+0.1153	-0.5902
26	+0.5416	-0.0008	-0.0318	+0.0011	-0.2891	+0.4616
27	-0.4861	-0.0179	-0.0446	+0.0046	-0.2126	-0.0982
28	+0.0025	+0.0590	-0.0028	+0.8559	+0.0096	+0.0077
29	-0.0096	+0.0945	-0.0066	-0.0811	+0.0124	+0.0077
30	+0.0162	+0.2647	+0.0266	-0.2779	-0.0127	-0.0342
31	-0.0161	-0.4723	-0.0183	-0.0505	-0.0187	+0.0138
32	+0.0053	-0.0086	-0.0063	-0.6026	+0.0171	+0.0175
33	-0.0222	-0.8820	-0.0167	-0.0582	-0.0044	-0.0038
34	+0.0095	+0.4830	+0.0113	-0.1228	-0.0075	-0.0092
35	-0.0180	-0.0358	-0.0331	+0.1456	+0.0017	+0.0196
36	+0.0201	+0.0842	+0.0280	+0.0132	+0.0070	-0.0079
37	-0.2338	+0.3165	-0.2154	-0.0256	-0.1968	+0.3986
39	-0.0252	-0.2215	-0.0196	-0.061	-0.0117	+0.0080
42	-0.2451	+0.3150	-0.1947	-0.0436	-0.1794	+0.3986
43	-0.0303	+0.1771	+0.0445	-0.0318	+0.1428	+0.1469
44	-0.2049	+0.2557	-0.0373	-0.0361	-0.1134	+0.4952

TABLE 2 (continued)

ROTATED-FACTOR MATRIX, UNINTERRUPTED FLOW

Variable	Factor M
1	-0.0025
3	-0.0078
4	+0.0024
6	-0.0085
7	+0.0159
9	-0.0044
10	+0.0087
11	-0.0118
12	+0.0359
13	+0.0048
14	-0.0100
15	+0.0001
16	-0.0005
17	-0.0141
18	-0.0307
19	-0.0072
20	-0.0085
21	-0.0203
22	-0.0160
23	+0.0089
24	-0.0042
25	-0.0199
26	+0.0176
27	-0.0078
28	-0.2780
29	+0.9610
30	-0.2198
31	-0.1997
32	-0.3467
33	-0.0720
34	+0.0420
35	-0.0211
36	+0.0206
37	-0.0183
39	-0.0812
42	-0.0276
43	-0.0365
44	-0.0294

along with its major component variables and their respec-
tive coefficient is included in the following list:

A - Commercial development - this factor includes a
high number of commercial establishments, access
drives, and related conditions indicating a high
degree of commerical development.

6 - Access drives on both sides, +0.9294

9 - Commercial establishments on both sides,
+0.9287

10 - Speed limit, -0.4930

11 - Shoulder width on right, +0.2341

12 - Shoulder width on left, +0.5259

26 - Signal in next section, +0.4114

27 - Signal in preceding section, +0.5888

B - Horizontal resistance - horizontal roadway features
influencing traffic movement are included in this
group.

13 - No-passing zone, +0.9244

16 - Average curvature, +0.7644

17 - Geometric modulus, -0.8693

18 - Stopping sight distance, -0.7443

19 - Practical capacity, -0.7638

20 - Possible capacity, -0.7556

C - Evening shopping travel - this category describes
late afternoon shopping trips on the evenings when
local stores are open.

       28 - Monday, +0.3523

       31 - Thursday, -0.6170

       32 - Friday, +0.4392

       33 - 8:00 to 10:00, -0.2464

       34 - 10:01 to 12:00, -0.7637

       36 - 3:01 to 6:00, +0.8724

D - Flat topography - a level roadway **alignment is**

    reflected in this factor.

       15 - Algebraic grade, -0.9151

       25 - Truck climbing lane, -0.6860

E - Time variations - this factor, which is not com-

    pletely defined, expresses variations in the times

    and the days when the data were collected.

       30 - Wednesday, -0.7612

       35 - 12:01 to 3:00, -0.8616

F - **Urban development - this category indicates that**

    the highway is located in an urban area.

       3 - Intersecting streets on both sides, +0.7510

       10 - Speed limit, -0.4368

       24 - Regulatory signs, +0.4697

G - Driver distractions - this group includes items

    which distract the driver's attention from the

    highway.

       21 - Advertising signs, +0.7895

       26 - Signal in next section, +0.5416

       27 - Signal in preceding section, -0.4861

H - Time variations - additional variations in times
are reflected in this factor.

31 - Thursday, -0.4723

33 - 8:00 to 10:00, -0.8820

34 - 10:01 to 12:00, +0.4830

I - Outbound traffic - traffic heading away from the
urban area is described by this factor.

23 - Information signs, -0.8789

24 - Regulatory signs, -0.5969

37 - Volume in direction of travel, -0.2154

J - Day-of-week variations - this factor, generated by
daily variations, is not completely discernible.

28 - Monday, +0.8559

30 - Wednesday, -0.2779

32 - Friday, -0.6026

K - Rural development - this group of variables describes
a rural-type highway with little roadside develop-
ment.

3 - Intersecting streets on both sides, -0.2194

9 - Commercial establishments on both sides,-0.2030

11 - Shoulder width on right, -0.9113

26 - Signal in next section, -0.2891

L - Stream friction - conditions which cause congestion
within the traffic stream are indicated by this
factor.

20 - Possible capacity, -0.5313

        25 - Truck climbing lane, -0.5902

        26 - Signal in next section, +0.4616

        37 - Volume in direction of travel, +0.3986

        44 - Volume to possible capacity ratio, +0.4952

  M - Day-of-week variations - this factor reflects

      further variations for different days of the week.

        28 - Monday, -0.2780

        29 - Tuesday, +0.9610

        32 - Friday, -0.3467

These factors were readily identified except for those
associated with time-of-day and day-of-week characteristics.
These variations resulted from the random selection of
different days and time periods for conducting the travel-
time studies.

The next execution in the factor-analysis procedure
was the computation of the factor-score matrix which is
presented in Table 3. The coefficients in this matrix
permit the factors to be evaluated as functions of the
original variables which are expressed in terms of multiple
linear regression equations. Examples of these equations
are presented later in the results.

The final step was the correlation of each factor
with the mean overall travel speed to determine those fac-
tors which significantly accounted for the variation in
travel speeds. These correlation coefficients are listed
in Table 4. The four factors which were significant at

TABLE 3

FACTOR-SCORE MATRIX, UNINTERRUPTED FLOW

Vari-able	Factor					
	A	B	C	D	E	F
1	+0.0094	-0.0158	+0.0162	+0.0239	+0.0270	+0.3878
3	-0.1070	-0.0267	+0.0017	-0.0310	+0.0012	+0.2954
4	+0.2498	+0.0372	-0.0088	+0.0191	-0.0106	+0.0182
6	+0.2064	+0.0245	-0.0078	+0.0372	-0.0065	-0.0784
7	+0.2438	+0.0440	-0.0133	+0.0147	-0.0198	-0.0070
9	+0.2068	+0.0246	-0.0071	+0.0363	-0.0088	-0.1012
10	-0.0002	+0.0099	+0.0269	+0.0512	+0.0242	-0.1190
11	-0.0774	-0.0446	+0.0152	+0.0752	+0.0067	-0.0316
12	+0.0951	+0.0031	+0.0042	-0.1563	-0.0177	+0.2558
13	+0.0523	+0.1909	-0.0298	-0.0125	-0.0194	-0.0018
14	+0.0508	+0.0679	+0.0306	-0.0041	+0.0486	-0.0235
15	-0.0218	+0.0015	-0.0095	-0.4695	-0.0222	+0.0785
16	+0.0620	+0.1468	+0.0048	-0.0069	+0.0099	+0.0295
17	-0.0234	-0.1760	+0.0077	-0.0409	+0.0125	-0.0127
18	+0.0427	-0.1128	+0.0105	-0.0252	+0.0365	-0.0337
19	-0.0018	-0.1602	+0.0133	+0.0090	+0.0108	+0.0832
20	-0.0090	-0.1348	+0.0430	+0.0285	+0.0480	+0.0702
21	+0.0901	+0.0373	+0.0287	+0.1444	+0.0437	+0.0633
22	+0.0251	+0.0511	-0.0052	-0.2618	-0.0002	-0.1444
23	+0.0087	+0.0720	-0.0245	+0.0644	-0.0371	-0.1214
24	-0.0064	-0.1067	+0.0051	+0.0371	-0.0039	+0.2535
25	+0.0337	-0.0028	+0.0190	-0.2814	+0.0209	+0.0939
26	-0.0157	-0.0264	-0.0027	-0.1736	-0.0060	-0.1106
27	+0.1930	+0.1018	-0.0189	+0.2162	-0.0297	+0.0680
28	-0.0052	-0.0066	+0.0407	+0.0046	+0.0955	+0.0057
29	+0.0015	+0.0020	+0.0321	+0.0006	+0.0224	-0.0070
30	+0.0044	+0.0007	-0.0215	-0.0091	-0.3546	+0.0069
31	+0.0088	+0.0149	-0.1613	-0.0062	+0.2439	-0.0153
32	-0.0153	-0.0164	+0.1671	+0.0176	+0.0961	+0.0123
33	+0.0194	+0.0200	+0.0503	-0.0163	+0.0351	-0.0142
34	-0.0037	-0.0025	-0.3478	+0.0034	+0.2714	+0.0058
35	+0.0115	+0.0207	+0.0155	-0.0089	-0.4371	-0.0231
36	-0.0171	-0.0267	+0.2637	+0.0138	+0.1213	+0.0229
37	+0.0173	+0.0109	+0.0496	-0.0224	+0.0732	-0.0226
39	+0.0181	-0.0259	-0.2669	-0.0156	+0.0051	-0.0196
42	+0.0220	+0.0054	+0.0623	-0.0217	+0.0736	-0.0139
43	+0.0403	+0.1847	+0.0313	-0.0259	+0.0445	-0.1049
44	+0.0305	+0.0955	+0.0349	-0.0475	+0.0476	-0.0522

TABLE 3 (continued)

FACTOR-SCORE MATRIX, UNINTERRUPTED FLOW

Vari-able	Factor					
	G	H	I	J	K	L
1	+0.0670	+0.0350	+0.0502	-0.0076	+0.1134	-0.1102
3	+0.0143	+0.0010	+0.0369	+0.0008	-0.0803	+0.0550
4	+0.0644	-0.0173	+0.0256	+0.0042	+0.1870	-0.0961
6	+0.1014	-0.0111	+0.0208	+0.0035	-0.0210	-0.0814
7	-0.0112	-0.0307	-0.0049	+0.0077	+0.1688	-0.0900
9	+0.0965	-0.0154	+0.0261	+0.0041	-0.0290	-0.0798
10	+0.1340	+0.0254	+0.0396	-0.0073	+0.1179	-0.1193
11	+0.0513	+0.0015	+0.1010	-0.0024	-0.5580	-0.0523
12	-0.0964	-0.0340	+0.1174	+0.0063	+0.0574	-0.0829
13	-0.0360	-0.0198	-0.0472	+0.0088	+0.0977	-0.0096
14	+0.0084	+0.0677	-0.0041	-0.0142	-0.0759	-0.3897
15	-0.0697	-0.0293	+0.0855	+0.0087	+0.1456	+0.1130
16	+0.0545	+0.0100	+0.0842	-0.0008	-0.0931	-0.2064
17	-0.0083	+0.0192	+0.1803	-0.0050	+0.0917	+0.1564
18	+0.0015	+0.0590	+0.1335	-0.0121	+0.1800	-0.0066
19	-0.0242	+0.0149	-0.0603	-0.0065	-0.1575	+0.0002
20	+0.0182	+0.0634	-0.0793	-0.0171	-0.1256	-0.2553
21	+0.5493	+0.0525	-0.1077	-0.0132	+0.0182	-0.1513
22	+0.0356	+0.0042	-0.0048	+0.0025	-0.2860	-0.0667
23	+0.0105	-0.0450	-0.6385	+0.0086	+0.0465	+0.0362
24	+0.0618	+0.0089	-0.4037	-0.0042	+0.0386	-0.0109
25	-0.1307	+0.0315	+0.0069	-0.0055	+0.0380	-0.2502
26	+0.3901	-0.0115	+0.0409	+0.0020	-0.1460	+0.2362
27	-0.3253	-0.0427	-0.1195	+0.0099	-0.0008	-0.2523
28	+0.0172	+0.0657	+0.0092	+0.6885	+0.0025	-0.0134
29	-0.0080	-0.0479	-0.0074	-0.0527	-0.0017	+0.0005
30	-0.0037	+0.1670	+0.0139	-0.2369	-0.0016	-0.0075
31	-0.0367	-0.1866	-0.0316	-0.0116	+0.0010	+0.0440
32	+0.0471	-0.0503	+0.0191	-0.5232	-0.0011	-0.0321
33	-0.0624	-0.5753	-0.0428	-0.0687	+0.0084	+0.0502
34	+0.0174	+0.4893	+0.0163	-0.0178	+0.0008	-0.0096
35	-0.0599	-0.0720	-0.0535	+0.0976	+0.0188	+0.0562
36	+0.0710	-0.0553	+0.0552	-0.0316	-0.0220	-0.0680
37	-0.1186	+0.1219	-0.1434	-0.0172	-0.0227	+0.1135
39	-0.0697	-0.0133	-0.0463	-0.0051	+0.0192	+0.0637
42	-0.1294	+0.1163	-0.1163	-0.0333	-0.0041	+0.1144
43	-0.0494	+0.0648	+0.0027	-0.0249	+0.1384	+0.0477
44	-0.1372	+0.0793	-0.0330	-0.0238	+0.0592	+0.1719

TABLE   3   (continued)

FACTOR-SCORE MATRIX, UNINTERRUPTED FLOW

Variable	Factor M
1	-0.0216
3	-0.0113
4	+0.0033
6	-0.0023
7	+0.0192
9	+0.0026
10	-0.0029
11	-0.0030
12	+0.0339
13	+0.0086
14	-0.0234
15	+0.0110
16	-0.0034
17	-0.0170
18	-0.0405
19	-0.0071
20	-0.0222
21	-0.0378
22	-0.0014
23	+0.0233
24	-0.0087
25	-0.0206
26	+0.0212
27	+0.0039
28	-0.2310
29	+0.7829
30	-0.1701
31	-0.1554
32	-0.3027
33	+0.0219
34	-0.0593
35	+0.0439
36	+0.0024
37	-0.0398
39	-0.0558
42	-0.0472
43	-0.0459
44	-0.0402

TABLE 4

CORRELATION OF MEAN TRAVEL SPEED WITH
FACTORS, UNINTERRUPTED FLOW

Factor	Correlation Coefficient
A	-0.5507^{*}
B	-0.0525
C	-0.0928
D	$+0.0049$
E	-0.0659
F	-0.1874^{*}
G	$+0.0956$
H	-0.0920
I	$+0.0535$
J	$+0.0289$
K	$+0.1744^{*}$
L	-0.2674^{*}
M	-0.0400

* Significant at the 5-percent level

the 5-percent level were, in their order of importance,
commercial development, stream friction, urban development,
and rural development. The correlation coefficients also
serve as multiple linear regression coefficients of the
factors. Thus, the following multiple linear regression
equation was evolved to predict mean travel speeds from the
significant factors:

13. $S_1 = 42.30 + 9.185 \, (-0.5507F_A \, -0.1874F_F \, +0.1744F_K$

$-0.2674F_L)$

where S_1 = mean travel speed, mph,

F_A = commercial development,

F_F = urban development,

F_K = rural development, and

F_L = stream friction.

The multiple correlation coefficient of this expression was
0.664. Approximately 44 percent of the total variation in
travel speeds were explained by the four factors. The
precision of the estimate was measured by the standard error
of estimate of 6.87 mph.

Multiple linear regression equations were developed to
evaluate the significant factors in terms of those variables
which predominantly explained each factor. The following
equations were written from the coefficients in the factor-
score matrix:

14. $F_A = -0.1070Z_3 + 0.2498Z_4 + 0.2064Z_6 + 0.2438Z_7$

$+ 0.2068Z_9 + 0.1930Z_{27}$

15. $F_F = 0.3878Z_1 + 0.2954Z_3 - 0.1012 Z_9 - 0.1190Z_{10}$

$+ 0.2558Z_{12} - 0.1444Z_{22} - 0.1214Z_{23} + 0.2535Z_{24}$

$- 0.1106Z_{26} - 0.1049Z_{43}$

16. $F_K = + 0.1134Z_1 + 0.1870Z_4 + 0.1688Z_7 + 0.1179Z_{10}$

$- 0.5580Z_{11} + 0.1456Z_{15} + 0.1800Z_{18} - 0.1575Z_{19}$

$- 0.1256Z_{20} - 0.2860Z_{22} - 0.1460Z_{26} + 0.1384Z_{43}$

17. $F_L = - 0.1102Z_1 - 0.1193Z_{10} - 0.3897Z_{14} + 0.1130Z_{15}$

$- 0.2064Z_{16} + 0.1564Z_{17} - 0.2553Z_{20}$

$- 0.1513Z_{21} - 0.2502Z_{25} + 0.2362Z_{26}$

$- 0.2523Z_{27} + 0.1135Z_{37} + 0.1144Z_{42}$

$+ 0.1719Z_{44}$

where F_i = common factor, and

Z_i = standard score of variable.

The values of the dependent and independent variables in these equations are expressed in standard-score form.

Standard scores are computed by the following relationship:

18. $Z_i = (X_i - \bar{X}_i) / s_i$

where Z_i = standard score of variable,

X_i = observed value of variable,

$\bar{X}_i$ = grand mean of variable, and

s_i = standard deviation of variable.

The grand means and standard deviations for each variable are listed in Table 13, Appendix B.

Multiple Linear Regression and Correlation Analysis

The second phase of the multivariate analysis of uninterrupted-flow conditions was the development of a multiple linear regression equation to predict mean travel speed from the significant variables. The 38 variables in the revised correlation matrix were included in a buildup regression technique. (32) The routine was first performed without weighting any of the variables. This procedure causes the variables to be entered into the equation in the order of their importance. The most significant variables were total volume, commercial establishments, and inter-secting streets, which were all closely related to the four significant factors. With these variables held in the equation by the weighting option of the computer program, different combinations of the remaining variables were

examined to maximize the criteria listed in the discussion
of the analysis.

The following multiple linear regression equation was
selected as the most valid functional relationship for the
estimation of overall travel speed.

19. $S_2 = 68.60 - 0.4541X_3 - 0.1775X_9 - 0.1007X_{13}$

$- 0.0150X_{19} - 0.0301X_{42}$

where S_2 = mean travel speed, mph

X_3 = intersecting streets on both sides,
number per mile,

X_9 = commercial establishments on both
sides, number per mile,

X_{13} = portion of section length where
passing was not permitted, percent,

X_{19} = practical capacity, vph, and

X_{42} = total traffic volume, vph.

The various statistics of this regression equation are
summarized in Table 5. The measure of correlation was ex-
pressed by a multiple correlation coefficient of 0.704.
The variables intersecting streets, commercial establish-
ments, no-passing zone, practical capacity, and total volume
accounted for 50 percent of the total variation in overall
travel speeds for the uninterrupted flow sections of the
bypass. The standard error of estimate of 6.55 mph was a

TABLE 5

MULTIPLE LINEAR REGRESSION AND CORRELATION
ANALYSIS, UNINTERRUPTED FLOW

Dependent Variable: Travel Speed

Intercept = 68.60 mph

Multiple Correlation Coefficient = 0.704

Standard Error of Estimate = 6.55 mph

Variable	Net Regression Coefficient	Standard Error
3	-0.4541	0.1214
9	-0.1775	0.0211
13	-0.1007	0.0135
19	-0.0150	0.0022
42	-0.0301	0.0044

measure of the precision of the equation. This multiple
linear regression equation is more reliable and appropriate
than the factor equation for predicting mean travel speeds
on the bypass, as values for the variables are easier to
obtain.

A significant portion of the unexplained variation in
overall travel speeds was probably caused by individual
driver behavior. Variations were evident in the driving
habits of vehicle operators as the test-car driver attempted
to relate his speed to the average speed of the traffic
stream. In addition, variations occurred within the test
driver in his reactions to the many conditions influencing
his speed.

Interrupted Flow

The analysis of interrupted flow followed the same
pattern as the investigation of uninterrupted flow. Mean
overall travel speeds and mean running speeds were com-
puted for directional flows and for the combined flows in
each section. These mean speeds are presented in Table 6.
The overall speed equaled the running speed in the north-
west flow of Section 1 because no stop was required in
this direction. The mean speeds in Sections 17 and 18
were higher than for the other sections; these sections
were longer and the delays caused by the signal were
distributed over a greater distance. Of the five sections

TABLE 6

AVERAGE TRAVEL SPEEDS, INTERRUPTED FLOW

Section	Average Travel Speed, mph					
	SE Flow		NW Flow		Combined Flows	
	Overall Speed	Running Speed	Overall Speed	Running Speed	Overall Speed	Running Speed
1*	26.8	29.5	42.4	42.4	34.6	36.0
3	30.1	31.9	29.3	32.2	29.7	32.1
8	21.7	26.4	24.1	28.2	22.9	27.3
11	19.9	25.3	27.4	30.0	23.7	27.7
13	23.6	25.9	24.8	27.8	24.2	26.9
15	19.7	23.5	21.1	25.7	20.4	24.6
17*	35.0	38.0	32.0	35.7	33.5	36.9
18*	29.2	32.9	24.1	31.9	26.7	32.4

* Not included in the multivariate analysis

included in the multivariate analysis, Section 1, which had a semi-actuated traffic signal (for the traffic on the road crossing the bypass), had the highest overall travel speeds.

The stopped times for each section were summarized by computing the mean stopped time of each run, the mean duration of the stop, and the percent of the runs when stops occurred. These results are presented in Table 7. Because a stop sign existed in the southeast flow of Section 1, the test vehicle was always forced to stop. The stopped times were less at Section 3 with the semi-actuated signal than at any other signal. In Section 11 the test vehicle encountered fewer stopped times in the northwest flow, as there was a 10-sec advance cycle for left turns and through movements in that direction. The test vehicle stopped more times heading Northwest than Southeast in Sections 17 and 18. Vehicles arrived in a random fashion in the northwest flow, but traffic in the southeast direction was grouped in platoons formed at the preceding signals. The signals in these two sections were not interconnected.

The average delays per vehicle for both bypass approaches to each intersection included in the multivariate analysis were computed by the two methods described in the discussion of the procedure. These total delays, including both stopped and running delays, are summarized in Table 8. The delays computed by the two methods were quite similar. A hypothesis test was performed to determine whether the mean of the differences of the computed and the theoretical mean

TABLE 7

AVERAGE STOPPED TIMES, INTERRUPTED FLOW

Section	SE Flow			NW Flow		
	Average Stopped Time per Run, sec	Average Length of Stop, sec	Percent of Runs When Stops Occurred	Average Stopped Time per Run, sec	Average Length of Stop, sec	Percent of Runs When Stops Occurred
1[*]	5.3	5.3	100.0	---	---	---
3	3.7	12.4	30.0	4.1	15.3	27.5
8	10.0	16.6	60.0	8.1	15.0	52.5
11	12.1	18.7	65.0	4.2	10.5	40.0
13	4.8	11.4	42.5	5.7	12.8	45.0
15	9.2	17.5	52.5	8.6	16.5	55.0
17[*]	5.3	16.4	32.5	8.0	16.3	60.0
18[*]	8.8	17.6	50.0	15.8	19.6	72.5

[*] Not included in the multivariate analysis.

TABLE 8

AVERAGE DELAYS, INTERRUPTED FLOW

| Section | Average Delay per Vehicle, sec | | | |
| | SE Flow | | NW Flow | |
	Calculated	Theoretical	Calculated	Theoretical
3	7.0	6.4	7.4	7.9
8	11.0	15.7	15.1	12.9
11	15.5	16.4	8.3	8.5
13	8.3	7.9	10.6	8.9
15	13.5	14.2	13.0	12.7

delays at each approach was equal to zero. The hypothesis was accepted for a 5-percent level of significance. Therefore, the results of the two computational methods did not differ significantly. Delays were then computed from the travel-time data for each test-car run. The greatest delays occurred at Sections 8 and 15 for both flows, and Section 11 for the southeast flow. The relative delays for each section corresponded closely to the stopped times.

Factor Analysis

The correlation matrix including variables 46 to 93 inclusive was computed and examined. The correlations of travel speed and delay with the other variables are listed in Table 17, Appendix B. Variables 53, 57, 59, 69, and 70 and the dependent variables 92 and 93 were deleted, and the resultant matrix was factorized by the principal-axes method. The factor analysis reduced the 41 variables to 11 factors which accounted for 90 percent of the total variance of the variables. The eigenvalue and that portion of the variation explained by each factor are listed in Table 18, Appendix B.

An examination of the rotated-factor matrix, presented in Table 9, permitted the identification of each factor. The following factors and their important component variables and respective coefficients were identified:

TABLE 9

ROTATED-FACTOR MATRIX, INTERRUPTED FLOW

Vari-able	Factor					
	N	O	P	Q	R	S
46	-0.1049	+0.1374	+0.1544	+0.1779	+0.8646	-0.0197
47	+0.2287	+0.0517	+0.1546	-0.9171	-0.0087	-0.1977
48	+0.0776	+0.0269	-0.9907	-0.0386	-0.0141	+0.0791
49	-0.4420	+0.0752	-0.8034	+0.0473	+0.0019	+0.0306
50	-0.5348	+0.1076	+0.1822	-0.0049	+0.3118	+0.0560
51	-0.0188	-0.0050	-0.6335	+0.1236	+0.0169	+0.1924
52	-0.0971	-0.0216	-0.3926	+0.3808	+0.0031	+0.2634
54	-0.4668	+0.0837	+0.1931	-0.0146	+0.0939	+0.7793
55	-0.9117	+0.1269	+0.2049	+0.0519	-0.0063	+0.1687
56	+0.2590	-0.1066	+0.3303	+0.3520	-0.0698	-0.0807
58	+0.4094	-0.1586	+0.5106	+0.7022	-0.0776	+0.0188
60	-0.0402	-0.0336	+0.4861	+0.6838	+0.2297	+0.1222
61	-0.0753	-0.0411	+0.6030	+0.7244	+0.2648	+0.0469
62	+0.6592	-0.1652	-0.1163	-0.0724	-0.6240	+0.03??
63	+0.3961	-0.1291	+0.1705	-0.1674	-0.1472	-0.1079
64	+0.8350	-0.0243	-0.0861	-0.3418	+0.3992	-0.0628
65	+0.2108	+0.1115	+0.2180	-0.8314	+0.2960	-0.0582
66	+0.0776	+0.0269	-0.9907	-0.0386	-0.0141	+0.0791
67	-0.2853	-0.1003	+0.3044	+0.2566	-0.7578	+0.2124
68	-0.0968	+0.0460	-0.2988	+0.5504	+0.3742	-0.5078
71	-0.0926	-0.0389	+0.4561	-0.0300	-0.2975	-0.7392
72	-0.2625	-0.0373	-0.0515	+0.1294	-0.2851	+0.8801
73	-0.0045	-0.0441	-0.2366	+0.2573	-0.1354	+0.8243
74	+0.3832	+0.0073	+0.4336	-0.7704	+0.0211	-0.0932
75	+0.1727	-0.0147	-0.9293	+0.2698	-0.0139	-0.0110
76	-0.0482	-0.2928	-0.0161	-0.0288	+0.0461	-0.0177
77	-0.0068	-0.1398	-0.0116	-0.0060	+0.0097	+0.0319
78	+0.0121	+0.1189	+0.0102	+0.0064	-0.0132	-0.0087
79	+0.0939	+0.5827	+0.0269	+0.0606	-0.0898	+0.0032
80	-0.0774	-0.4199	-0.0162	-0.0486	+0.0720	-0.0107
81	+0.1264	+0.5865	+0.0284	+0.0676	-0.1053	+0.0431
82	-0.0019	+0.2506	-0.0036	+0.0203	-0.0240	-0.0381
83	+0.0508	+0.2590	+0.0058	+0.0293	-0.0374	+0.0150
84	-0.1095	-0.7629	-0.0174	-0.0801	+0.1133	-0.0000
85	-0.4059	-0.8230	+0.1038	+0.0155	-0.0736	+0.0667
86	+0.3018	-0.7167	-0.1170	+0.1954	-0.2029	-0.1599
87	+0.2793	-0.8030	+0.1067	+0.2206	-0.2913	-0.0318
88	+0.1228	+0.8029	+0.0287	+0.0849	-0.1270	+0.0010
89	+0.7013	-0.0126	+0.3616	-0.1583	+0.5359	-0.2178
90	+0.2246	-0.0142	+0.0173	-0.3756	+0.4257	+0.1869
91	+0.0721	-0.8524	+0.1420	+0.1334	-0.2302	+0.1063

TABLE 9 (continued)

ROTATED-FACTOR MATRIX, INTERRUPTED FLOW

Vari-able	Factor				
	T	U	V	W	X
46	-0.0020	+0.0188	+0.0026	+0.0192	+0.0045
47	+0.0012	-0.1810	+0.0024	-0.0007	+0.0062
48	+0.0007	-0.0274	-0.0126	-0.0039	-0.0153
49	-0.0043	+0.0433	+0.0438	+0.0236	+0.0446
50	+0.0124	+0.7288	-0.0293	-0.0011	-0.0304
51	+0.0055	+0.6978	-0.0024	-0.0044	-0.0017
52	-0.0012	+0.7365	+0.0179	+0.0109	+0.0145
54	-0.0008	-0.2291	-0.0202	-0.0016	-0.0095
55	-0.0032	-0.0173	+0.0061	+0.0198	+0.0162
56	-0.0004	+0.8096	+0.0233	+0.0083	+0.0100
58	-0.0058	+0.1568	+0.0222	+0.0031	+0.0100
60	-0.0054	-0.4504	+0.0010	-0.0017	+0.0114
61	-0.0014	+0.1578	+0.0068	+0.0051	+0.0046
62	-0.0172	-0.0401	+0.0526	+0.0208	+0.0321
63	-0.0130	-0.0426	+0.0437	+0.0163	+0.0252
64	+0.0020	-0.0365	-0.0033	-0.0084	-0.0110
65	+0.0037	-0.1565	-0.0437	-0.0073	-0.0411
66	+0.0007	-0.0274	-0.0126	-0.0039	-0.0153
67	-0.0153	-0.0876	+0.0519	+0.0276	+0.0386
68	+0.0079	+0.2465	-0.0745	-0.0243	-0.0539
71	-0.0085	-0.3017	+0.0378	+0.0127	+0.0518
72	-0.0015	-0.0001	+0.0237	+0.0014	+0.0212
73	+0.0043	+0.3475	-0.0232	-0.0097	-0.0405
74	-0.0015	-0.1963	+0.0170	+0.0019	+0.0187
75	-0.0011	+0.0853	-0.0108	-0.0012	-0.0194
76	+0.1308	+0.0095	-0.2212	+0.8456	+0.2427
77	+0.1422	+0.0007	+0.0663	-0.0586	-0.9225
78	-0.8219	-0.0000	+0.0383	-0.2491	+0.1768
79	+0.5977	-0.0121	+0.2300	-0.0953	+0.2653
80	+0.1752	+0.0024	-0.1744	-0.6064	+0.3217
81	+0.4812	-0.0166	-0.3519	-0.1240	+0.2051
82	+0.1770	+0.0324	+0.8699	-0.0994	-0.1175
83	-0.7767	-0.0176	-0.1566	+0.1674	+0.0772
84	+0.2603	-0.0060	-0.4207	+0.0107	-0.0658
85	+0.0774	-0.0768	+0.1496	+0.0128	+0.0853
86	+0.0819	+0.1725	-0.1149	-0.0504	-0.1299
87	+0.1025	+0.0779	-0.0806	-0.0137	-0.0281
88	+0.0301	+0.0098	+0.4160	-0.0777	+0.1251
89	-0.0007	-0.0171	+0.0082	+0.0020	+0.0019
90	-0.0533	-0.2679	+0.3943	+0.0524	+0.2180
91	+0.0805	-0.0747	+0.1577	+0.0140	+0.1030

N - High volume on major street - this factor describes
a signal designed to handle a predominantly through
movement of traffic for the major direction of flow.

55 - Intersecting streets on both sides, -0.9117

62 - Cycle length, +0.6592

63 - Green time per cycle, +0.8961

64 - Practical approach capacity, +0.8350

89 - Green to cycle ratio, +0.7013

O - Off-peak period - this condition indicates an off-
peak volume period of the day.

79 - Thursday, +0.5827

80 - Friday, -0.4199

81 - 8:00 to 10:00, +0.5865

84 - 3:01 to 6:00, -0.7629

85 - Approach volume, -0.8230

86 - Opposing volume, -0.7167

87 - Total intersection volume, -0.8031

91 - Approach volume to capacity ratio, -0.8525

P - Flat topography - this factor describes a level
type of topography.

51 - Approach grade, -0.6335

52 - Exit grade, -0.3926

Q - Commercial development - a high degree of commercial
development adjacent to the intersection is indicated
by this grouping of variables.

58 - Access drives on both sides, +0.7022

61 - Commercial establishments on both sides,
+0.7244

68 - Regulatory signs, +0.5504

R - Low minor-street traffic - this factor describes
an intersection with a relatively minor street
intersecting the major traffic flow.

46 - Semi-actuated signal, +0.8646

62 - Cycle length, -0.6240

87 - Total intersection volume, -0.2913

90 - Approach to total volume ratio, +0.4257

S - Concentrated turning movements - this factor
indicates a large percentage of turning movements
from both streams of the major traffic flow to the
right side of the direction of travel of the test
vehicle.

71 - Left turns from directional travel, -0.7392

72 - Right turns from directional travel, +0.8801

73 - Left turns from opposing travel, +0.8243

T - Time variations - variations in the times and days
when the data were recorded are reflected in this
factor, which is not completely defined.

78 - Wednesday, -0.8220

79 - Thursday, +0.5977

81 - 8:00 to 10:00, +0.4812

83 - 12:01 to 3:00, -0.7767

U - Vertical resistance - this group describes the
vertical alignment affecting the traffic flow.

50 - Length of exit merge lane, +0.7288

51 - Approach grade, +0.6978

52 - Exit grade, +0.7365

V - Long-distance travel - through traffic traversing
the entire length of the bypass is reflected in
this factor.

81 - 8:00 to 10:00, -0.3519

82 - 10:01 to 12:00, +0.8699

84 - 3:01 to 6:00, -0.4207

88 - Commercial vehicles, +0.4160

90 - Approach to total volume ratio, +0.3943

W - Day-of-week variations - the variation in days for
which travel times were obtained contribute to this
partially defined factor.

76 - Monday, +0.8456

78 - Wednesday, -0.2492

80 - Friday, -0.6065

X - Day-of-week variations - further variations within
the week are evident in this group.

77 - Tuesday, -0.9226

79 - Thursday, +0.2653

80 - Friday, +0.3217

Following the identification of each factor, the factor-
score matrix was computed. This matrix is presented in
Table 10.

TABLE 10

FACTOR-SCORE MATRIX, INTERRUPTED FLOW

Vari-able	Factor					
	N	O	P	Q	R	S
46	-0.0072	-0.0096	-0.0108	+0.0616	+0.2790	+0.0240
47	-0.0055	-0.0022	+0.0320	-0.2016	-0.0333	-0.0286
48	+0.0310	-0.0007	-0.1765	+0.0206	+0.0149	+0.0084
49	-0.0968	-0.0282	-0.1406	+0.0027	+0.0141	-0.0478
50	-0.1240	-0.0156	+0.0816	-0.1117	+0.0673	-0.0187
51	+0.0105	-0.0077	-0.0660	-0.0416	+0.0039	+0.0279
52	+0.0062	-0.0067	-0.0255	+0.0078	+0.0048	+0.0462
54	-0.0455	+0.0036	+0.0442	-0.0123	+0.0614	+0.2550
55	-0.1964	-0.0203	+0.0456	-0.0378	-0.0053	-0.0027
56	+0.0538	+0.0035	+0.0990	-0.0056	-0.0451	-0.0335
58	+0.1206	+0.0176	+0.0839	+0.1644	-0.0115	+0.0292
60	+0.0381	+0.0085	+0.0409	+0.2204	+0.1080	+0.0637
61	+0.0171	+0.0031	+0.0977	+0.1542	+0.0939	+0.0218
62	+0.1410	+0.0208	-0.0171	+0.0016	-0.1904	+0.0296
63	+0.1845	+0.0212	+0.0235	-0.0005	-0.0487	+0.0265
64	+0.1774	+0.0144	-0.0235	-0.0255	+0.1265	+0.0607
65	+0.0140	+0.0103	+0.0440	-0.1750	+0.0675	+0.0352
66	+0.0310	-0.0007	-0.1765	+0.0206	+0.0149	+0.0084
67	-0.0520	+0.0033	+0.0610	+0.0268	-0.2305	+0.0232
68	-0.0217	+0.0036	-0.0678	+0.1346	+0.1071	-0.1866
71	-0.0845	-0.0120	+0.0469	+0.0142	-0.1714	-0.2591
72	+0.0042	+0.0003	+0.0168	-0.0024	-0.0505	+0.2698
73	+0.0704	+0.0167	-0.0007	+0.0128	-0.0112	+0.2625
74	+0.0418	+0.0030	+0.0781	-0.1626	-0.0164	-0.0247
75	+0.0595	+0.0043	-0.1690	+0.0903	+0.0164	-0.0227
76	-0.0213	-0.0464	-0.0103	-0.0108	+0.0206	-0.0165
77	+0.0192	+0.0211	-0.0129	+0.0014	-0.0077	+0.0297
78	+0.0026	-0.0075	+0.0007	+0.0042	-0.0094	-0.0057
79	+0.0342	+0.1177	+0.0032	+0.0273	-0.0362	-0.0016
80	-0.0521	-0.1225	-0.0098	-0.0338	+0.0509	-0.0075
81	+0.0880	+0.1960	+0.0175	+0.0421	-0.0643	+0.0396
82	-0.0440	-0.0370	-0.0110	-0.0072	+0.0102	-0.0437
83	+0.0433	+0.0722	+0.0056	+0.0258	-0.0350	+0.0133
84	-0.0476	-0.1390	-0.0053	-0.0390	+0.0583	+0.0058
85	+0.0378	-0.1907	-0.0031	+0.0002	+0.0311	+0.0350
86	+0.0357	-0.1200	-0.0229	+0.0260	-0.0422	-0.0545
87	+0.0297	-0.1416	+0.0119	+0.0290	-0.0581	-0.0124
88	+0.0501	+0.1514	+0.0073	+0.0389	-0.0609	-0.0046
89	+0.1412	+0.0102	+0.0478	+0.0077	+0.1608	+0.0106
90	+0.0164	-0.0831	-0.0219	-0.0538	+0.1694	+0.0909
91	-0.0361	-0.2080	+0.0058	+0.0066	-0.0153	+0.0154

TABLE 10 (continued)

FACTOR-SCORE MATRIX, INTERRUPTED FLOW

Vari-able	Factor				
	T	U	V	W	X
46	+0.0085	−0.0326	+0.0225	+0.0131	+0.0165
47	+0.0051	+0.0493	−0.0040	−0.0055	−0.0018
48	+0.0014	−0.0747	−0.0026	−0.0008	−0.0019
49	+0.0013	−0.0317	+0.0726	+0.0249	+0.0650
50	+0.0080	+0.3066	+0.0290	−0.0017	+0.0170
51	−0.0018	+0.2274	+0.0244	+0.0029	+0.0331
52	−0.0064	+0.2289	+0.0367	+0.0173	+0.0433
54	+0.0066	−0.1007	−0.0321	−0.0144	−0.0274
55	+0.0049	+0.0081	+0.0413	+0.0119	+0.0278
56	−0.0110	+0.3171	+0.0252	+0.0175	+0.0293
58	−0.0124	+0.0117	−0.0145	+0.0090	−0.0082
60	−0.0011	−0.2488	−0.0240	−0.0051	−0.0185
61	−0.0032	+0.0073	+0.0033	+0.0060	+0.0021
62	−0.0186	+0.0006	−0.0071	+0.0256	+0.0014
63	−0.0129	+0.0129	−0.0147	+0.0104	−0.0043
64	+0.0018	−0.0034	−0.0333	−0.0077	−0.0215
65	+0.0099	+0.0351	−0.0425	−0.0162	−0.0433
66	+0.0014	−0.0747	−0.0026	−0.0008	−0.0019
67	−0.0145	−0.0192	+0.0219	+0.0270	+0.0148
68	+0.0040	+0.0133	−0.0183	−0.0165	−0.0165
71	−0.0060	−0.0561	+0.0432	+0.0163	+0.0406
72	−0.0022	−0.0282	−0.0074	−0.0038	+0.0010
73	−0.0021	+0.0772	−0.0425	−0.0112	−0.0395
74	+0.0020	+0.0382	−0.0098	−0.0032	−0.0026
75	−0.0028	−0.0601	−0.0026	+0.0053	−0.0036
76	+0.0883	+0.0151	−0.0263	+0.6813	+0.1983
77	+0.0557	−0.0358	−0.0098	−0.0369	−0.7222
78	−0.4045	+0.0118	+0.0183	−0.2254	+0.1297
79	+0.2968	+0.0024	+0.0755	−0.0316	+0.1876
80	+0.0677	+0.0069	−0.0898	−0.5271	+0.2848
81	+0.2496	−0.0208	−0.3403	−0.1063	+0.0939
82	+0.0704	+0.0321	+0.5573	+0.0009	−0.0452
83	−0.3657	−0.0061	−0.1143	+0.1107	+0.0208
84	+0.1214	−0.0117	−0.1936	−0.0367	−0.0208
85	+0.0183	−0.0222	+0.1744	+0.0087	+0.1124
86	+0.0208	+0.0402	−0.0240	−0.0555	−0.0675
87	+0.0304	+0.0176	+0.0056	−0.0259	+0.0093
88	+0.0195	+0.0133	+0.1769	−0.0108	+0.0672
89	+0.0011	+0.0135	−0.0159	+0.0017	−0.0088
90	−0.0243	−0.0664	+0.2897	+0.0643	+0.1943
91	+0.0189	−0.0238	+0.1973	+0.0094	+0.1342

The factors were correlated with both mean travel
speed and mean delay; these factor correlations are listed
in Table 11. The same three factors were signifiant at the
5-percent level in accounting for the variations of both
dependent variables. These factors were off-peak period,
flat topography, and low minor-streettraffic. Multiple
linear regression equations were developed to predict
travel speed and delay from these significant factors. The
following relationship was derived to estimate travel speed
for interrupted flow:

$$20. \quad S_3 = 24.16 + 10.186 \ (0.2202F_0 + 0.1404F_P + 0.2676F_R)$$

where S_3 = mean travel speed, mph,

F_0 = off-peak period,

F_P = flat topography, and

F_R = low minor-street traffic.

The degree of correlation of this equation was expressed
by a multiple correlation coefficient of 0.364. Approxi-
mately 13 percent of the total variation in travel speed
was reflected in the three significant factors. The standard
error of estimate was 9.49 mph.

Delay was related to the significant factors by the
following formula:

TABLE 11

CORRELATION OF MEAN TRAVEL SPEED AND DELAY WITH

FACTORS, INTERRUPTED FLOW

Factor	Correlation Coefficient	
	Travel Speed	Delay
N	-0.0278	-0.0646
O	+0.2022*	-0.1455*
P	+0.1404*	-0.1778*
Q	-0.0703	+0.0470
R	+0.2626*	-0.2044*
S	-0.0194	+0.0399
T	+0.0137	+0.0120
U	-0.0540	+0.0224
V	-0.0413	+0.0164
W	+0.0567	-0.0636
X	+0.0388	-0.0583

* Significant at the 5-percent level

21. $D_1 = 16.49 + 14.23 \ (-0.1455F_0 \ -0.1778F_P \ -0.2044F_R)$

where D_1 = mean delay, sec,

F_0 = off-peak period,

F_P = flat topography, and

F_R = low minor-street traffic.

The multiple correlation coefficient of 0.307 measured the degree of linear association between delay and the three significant factors. The three factors explained only 9 percent of the total variation in delays. An index of precision was provided by the standard error of estimate of 13.54 sec.

The significant factors were evaluated in terms of the original study variables. The following multiple linear regression equations were developed in standard-score form to express these factors:

22. $F_0 = 0.1177Z_{79} - 0.1225Z_{80} + 0.1960Z_{81} - 0.1390Z_{84}$

$- 0.1907Z_{85} - 0.1200Z_{86} - 0.1416Z_{87}$

$+ 0.1514Z_{88} - 0.2080Z_{91}$

23. $F_P = -0.1765Z_{48} - 0.1406Z_{49} - 0.1765Z_{66} - 0.1690Z_{75}$

24. $F_R = 0.2790Z_{46} + 0.1080Z_{60} - 0.1904Z_{62} + 0.1265Z_{64}$

$$- 0.2305Z_{67} + 0.1071Z_{68} - 0.1234Z_{71} + 0.1608Z_{89}$$

$$+ 0.1694Z_{90}$$

where F_j = common factor and

Z_i = standard score of variable.

The standard scores of each variable are computed from Equation 18. The means and standard deviations of each variable are listed in Table 16, Appendix B.

Multiple Linear Regression and Correlation Analysis

Multiple linear regression equations were developed to estimate travel speeds and delays for interrupted flow as functions of the significant variables. The techniques for deriving these relationships were similar to the standards followed in the uninterrupted flow analysis.

The multiple linear equations expressing overall travel speed and delay as functions of the significant variables are presented in Table 12. The speed relationship has the following form:

25. $S_4 = 28.595 - 0.4165X_{51} - 0.2118X_{62} - 0.0120X_{85}$

$$- 0.0170X_{87} + 29.4800X_{89}$$

where S_4 = mean travel speed, mph,

TABLE 12

MULTIPLE LINEAR REGRESSION AND CORRELATION

ANALYSIS, INTERRUPTED FLOW

Dependent Variable : Travel Speed

Intercept = 28.59 mph

Multiple Correlation Coefficient = 0.368

Standard Error of Estimate = 9.53 mph

Variable	Net Regression Coefficient	Standard Error
51	-0.4165	0.3235
62	-0.2118	0.0587
85	-0.0120	0.0280
87	-0.0170	0.0104
89	+29.4800	7.4789

TABLE 12 (continued)

MULTIPLE LINEAR REGRESSION AND CORRELATION

ANALYSIS, INTERRUPTED FLOW

Dependent Variable: Travel Delay

Intercept = 11.95 sec

Multiple Correlation Coefficient = 0.326

Standard Error of Estimate = 13.544 mph

Variable	Net Regression Coefficient	Standard Error
49	+0.0052	0.0024
62	+0.2299	0.0833
85	+0.0135	0.0401
87	+0.0168	0.0154
89	-35.7935	12.7107

$$X_{51} = \text{average algebraic grade of approach, percent,}$$

$$X_{62} = \text{cycle length of traffic signal, sec,}$$

$$X_{85} = \text{traffic volume approaching the intersection in the direction of travel, vehicles per 15 min,}$$

$$X_{87} = \text{total traffic volume entering the intersection on all four approaches, vehicles per 15 min, and}$$

$$X_{89} = \text{green time to cycle length ratio.}$$

The degree of linear correlation was indicated by a multiple correlation coefficient of 0.368. The significant variables (approach grade, cycle length, approach volume, total intersection volume, and green-to-cycle ratio) accounted for 14 percent of the variation in travel speeds. The reliability of the estimate was expressed by a standard error of 9.53 mph.

The following multiple linear regression equation for travel delay was evolved:

$$26. \quad D_2 = 11.951 + 0.0052X_{49} + 0.2299X_{62} + 0.0135X_{85}$$

$$+ 0.0168X_{87} - 35.7935X_{89}$$

where D_2 = mean travel delay, sec,

X_{49} = length of approach to special turning lane, ft,

X_{62} = cycle length of traffic signal, sec,

X_{85} = traffic volume approaching the intersection in the direction of travel, vehicles per 15 min,

X_{87} = total traffic volume entering the intersection on all four approaches, vehicles per 15 min, and

X_{89} = green time to cycle length ratio.

The correlation coefficient of 0.326 measured the degree of the functional relationship of the variables. Approximately 11 percent of the variability in delay was explained by the independent variables. These five variables were length of approach to turning lane, cycle length, approach volume, total intersection volume, and green-to-cycle ratio. The standard error of estimate was 13.54 mph. The sign of the regression coefficient of the length of approach to turning lane variable was contrary to expectation. The plus sign indicated that delay increased as the length of the approach increased in combination with the other variables in the model. The length of the approach, however, was associated with a high-volume intersection and with a relatively high number of turning movements. These conditions contributed to the increased delays.

The multiple correlation coefficients of these two
regression equations were lower for the analysis of the
interrupted flow versus those for the uninterrupted flow.
Overall travel speeds and delays at signalized intersections
depended greatly on whether or not the vehicle was required
to stop. This condition of chance was not accounted for in
the analysis. In addition, those variables which were
significant in the final models exhibited little variation
among the study intersections. The unexplained variability
with individual drivers was again evident in the analysis.

Recommended Improvements

The results of the analyses of uninterrupted and
interrupted flow were applied for the recommendation of
traffic engineering improvements to minimize delays on the
U.S. 52 Bypass. The major delays to the traffic stream
occurred at the signalized intersections. These delays
are evident by an examination of the average travel speeds
for all sections depicted in Figure 5. The significant
factors in causing the delays were largely associated with
the design of the signal and the approach volumes. Reduc-
tions in speed for the uninterrupted flow portions of the
bypass were mainly influenced by the degree of commercial
development, the related number of access points, and by
volume. The annual average daily traffic of each section
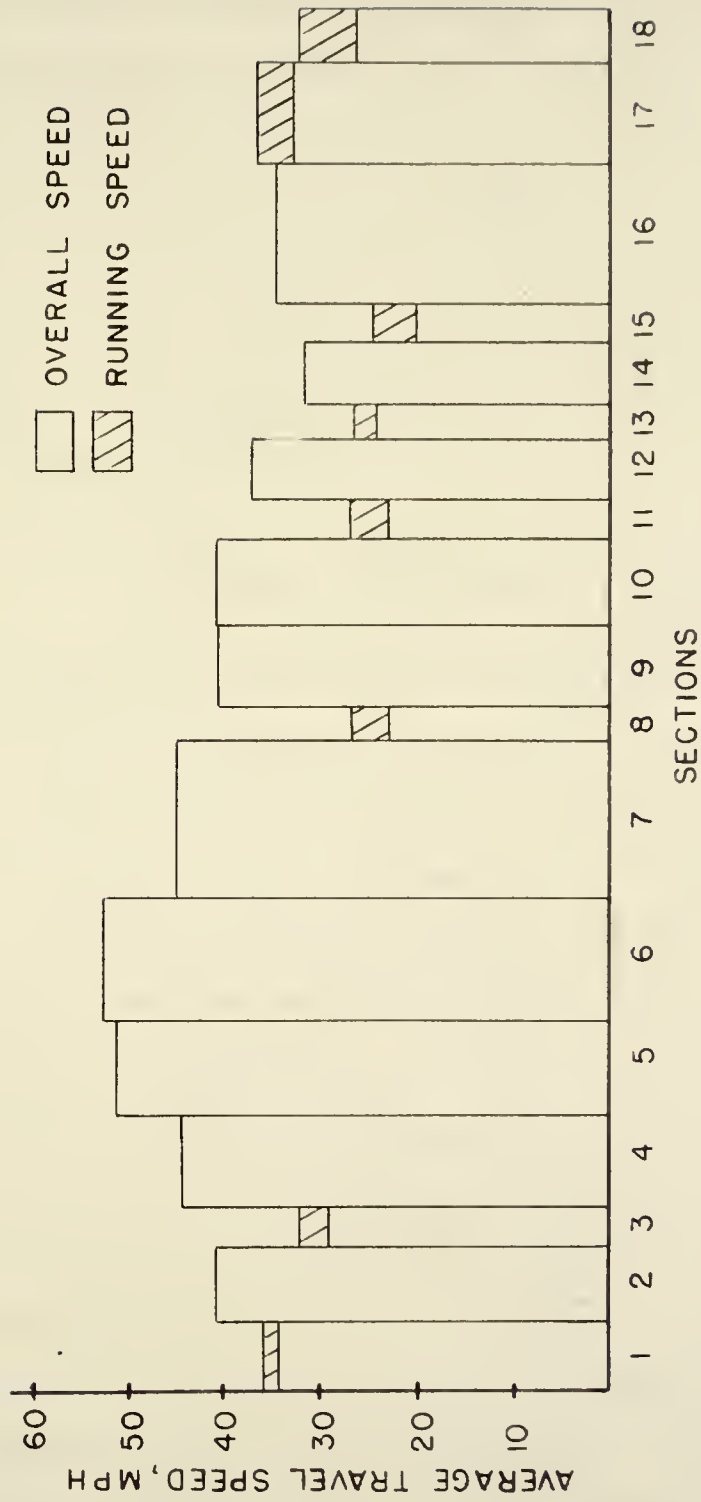
FIGURE 5   AVERAGE TRAVEL SPEEDS FOR SECTIONS

is shown in Figure 6. The lack of capacity of the two-lane highway was also evident in the peak-hour periods.

In compliance with these general conclusions, the following recommendations were made to aid in reducing delays. Certain modifications are first presented for immediate implementation at minimum cost. These improvements are to serve until a long-range plan of complete reconstruction is carried out. A second group of recommendations apply to such reconstruction.

Short-Range Improvements

The following traffic engineering techniques are suggested for immediate consideration to minimize delays and increase overall travel speed on the U.S. 52 Bypass.

1. The design of the existing traffic signals should be carefully reviewed with consideration given to the proper assignment of green time for all intersection approaches.

2. Turning lanes at the signalized intersections should be improved and clearly marked. Lanes should be designated for the proper traffic movements.

3. Entrances to commercial establishments should be limited and clearly channelized. In many cases, drivers can presently leave the highway at any

FIGURE 6   ANNUAL AVERAGE DAILY TRAFFIC
FOR SECTIONS

point along a continuous shoulder in front of
various commercial establishments.

4.   Additional traffic signals should be installed
only if they are fully warranted.

Long-Range Improvements

The following items are recommended as major considera-
tions in conjunction with reconstruction of the highway.

1.   The bypass should be reconstructed as a four-lane
highway with a median to provide additional
capacity.

2.   Median left-turn lanes should be constructed at all
intersections with left turns permitted only at
these points.

3.   The number of new access points on the bypass
should be strictly limited to those which are
absolutely necessary. Wide shoulders should be
provided at access drives to minimize turning
conflicts with the major flow of traffic.

SUMMARY OF RESULTS AND CONCLUSIONS

The following conclusions were derived from the results
of the multivariate analyses of overall travel speed and
delay on the U.S. 52 Bypass located in Lafayette, Indiana.
The movements of traffic on the bypass were classified by
two categories. Uninterrupted flow was distinguished from
interrupted flow at signalized intersections where traffic
was required to stop for the red-signal indication. These
conclusions are valid only for the flow of traffic on the
bypass, but these findings also serve as generalizations
of the significant determinants of travel speeds and delays
on similar type facilities.

1. The overall travel speeds of the uninterrupted-
   flow portions of the bypass were influenced by
   four significant factors. Commercial develop-
   ment, urban development, and stream friction were
   negatively related to speed, and the remaining
   factor, rural development, was associated with
   travel speed in a positive manner. Commercial
   development accounted for 30 percent of the
   variation in travel speed.

2. Five variables were significant in the prediction of mean overall travel speeds for the uninterrupted flow sections. These variables, which were total number of street intersections per mile, total number of commercial establishments per mile, percent of section where passing was not permitted, practical capacity, and total volume, were all negatively related with travel speed.

3. For the interrupted-flow portions the factors which significantly explained both overall travel speeds and delays were off-peak period, flat topography, and low minor-street traffic. These three factors were associated with increased travel speeds and decreased delays.

4. The variables of cycle length, traffic volume approaching the intersection in the direction of travel, and total intersection volume contributed to decreased speeds and increased delays. The green time to cycle length ratio accounted for significant variations in travel speeds and delays in a positive and negative manner, respectively. The approach grade of the intersection was negatively related to speed, and the length of the approach to the turning lane was positively associated with delay.

5. Multiple linear regression equations were developed to estimate mean travel speeds and delays from the significant factors and variables for both flows. Approximately 50 percent of the variation in speed of uninterrupted flow was explained and 10 to 15 percent of the variation in travel speeds and delays at signalized intersections was accounted for. The reliability of these relationships was limited by the unknown effects of driver behavior which was not included in the analysis. In addition, delays at traffic signals were largely dependent on whether or not a stop occurred.

SUGGESTIONS FOR FURTHER RESEARCH

The findings of this investigation have brought about several possibilities for further research. The following items are suggested for continued study.

1. The multiple linear regression equations to predict mean travel speeds for uninterrupted and interrupted flows should be verified on another two-lane, urban highway. These statistical models may be valid as reliable estimators of travel speeds on similar types of highways.

2. Similar multiple linear regression models should be developed for multi-lane highways in urban areas. Different groups of factors and variables with adjusted coefficients and intercepts may adequately describe the flow of traffic on multi-lane facilities.

3. The analysis of interrupted flow at signalized intersections should be expanded to include a larger sample of intersection conditions. A greater range in the values of the significant variables should produce a more reliable multiple linear regression equation.

4. Non-linear forms of the variables and interaction
    terms may increase the precision of the estimates
    of travel speeds and delays. The statistical
    models developed in this study did not include
    curvilinear or joint functional relationships.

5. After the bypass has been reconstructed, travel-
    speed and delay data should be collected and analyzed
    again to determine the effects of the improvements.
    Statistical models developed for this facility
    could form the basis of travel-speed predictions
    for multi-lane, urban highways.

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31. "Factor Analysis," BIMD 3M, Statistical Laboratory Library Program, Purdue University.

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APPENDICES

APPENDIX A

TEST SECTIONS, U.S. 52 BYPASS
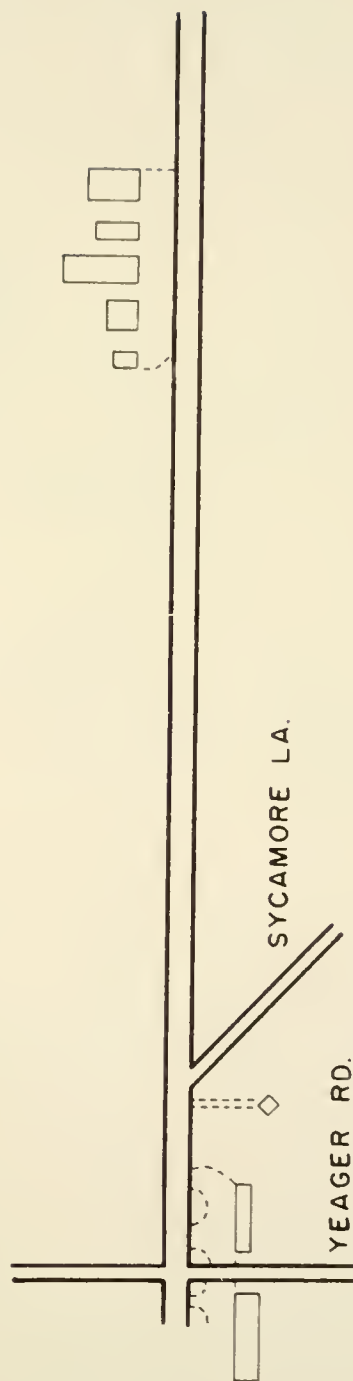
(SCALE 1" = 300')

N

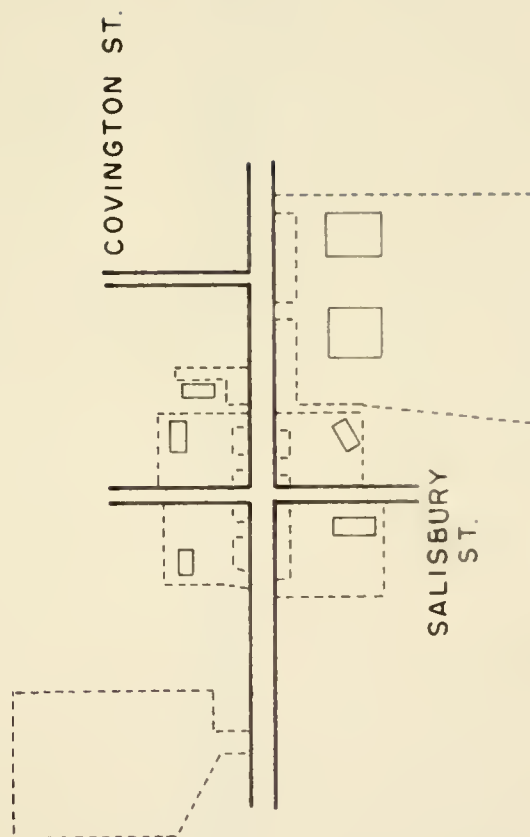U.S. 52 BYPASS

BUSINESS ROUTE
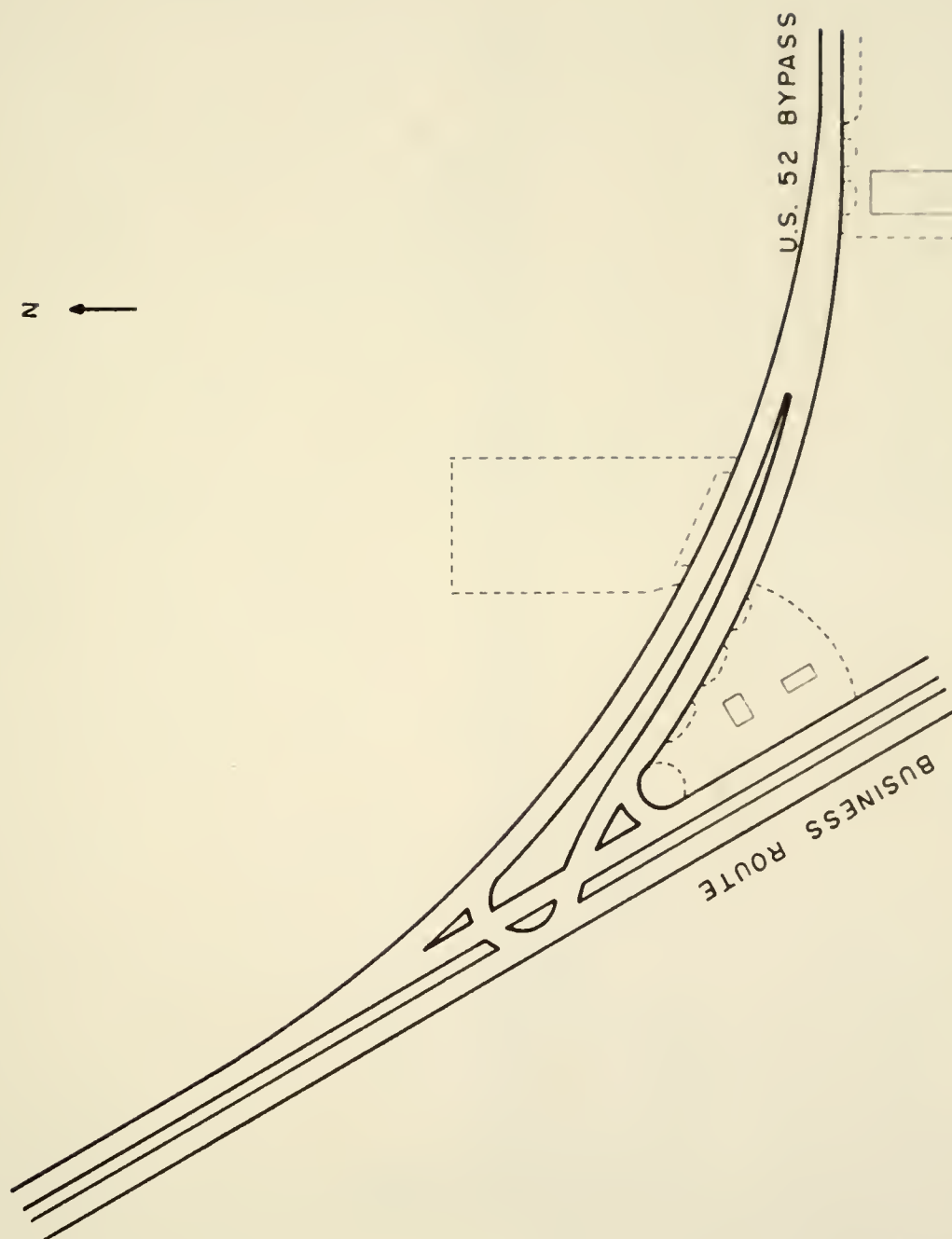
FIGURE 7   BYPASS, SECTION I

N

SYCAMORE LA.

YEAGER RD.

FIGURE 8   BYPASS, SECTION 2

FIGURE 9   BYPASS, SECTION 3

TRUCK CLIMBING LANE

HAPPY HOLLOW RD.

N
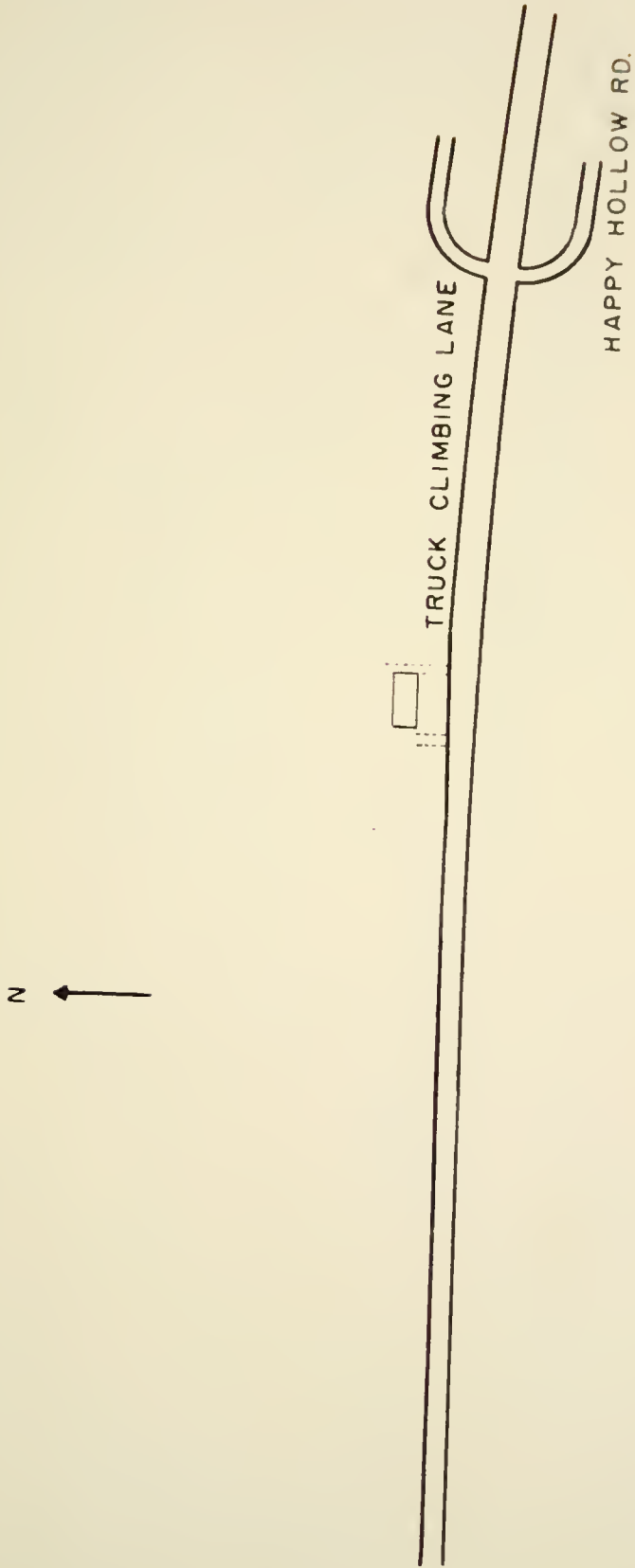
FIGURE 10   BYPASS, SECTION 4

TRUCK CLIMBING LANE

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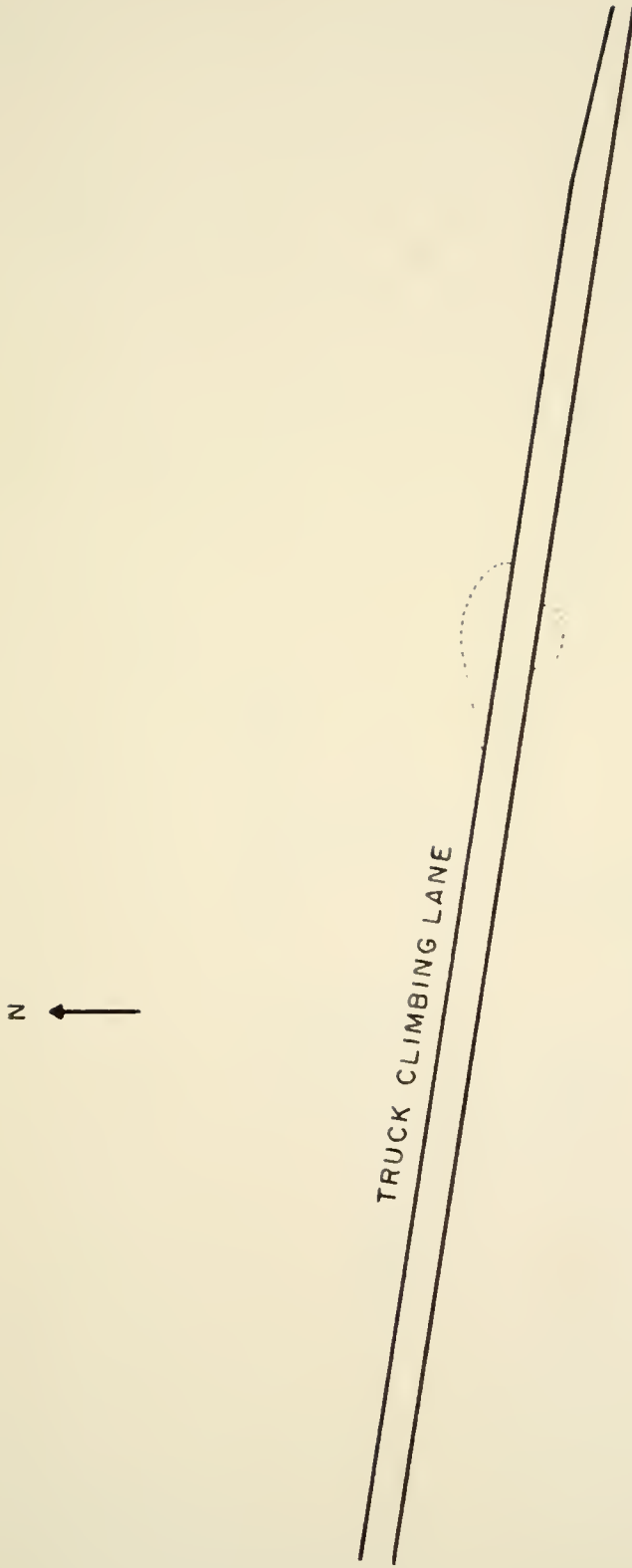
FIGURE 11   BYPASS, SECTION 5

WABASH RIVER

N ←
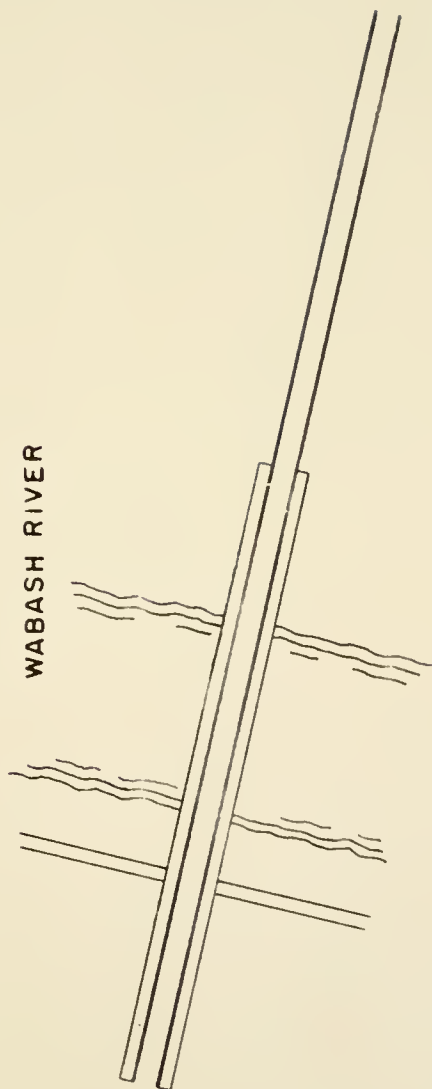
FIGURE 12   BYPASS, SECTION 6A
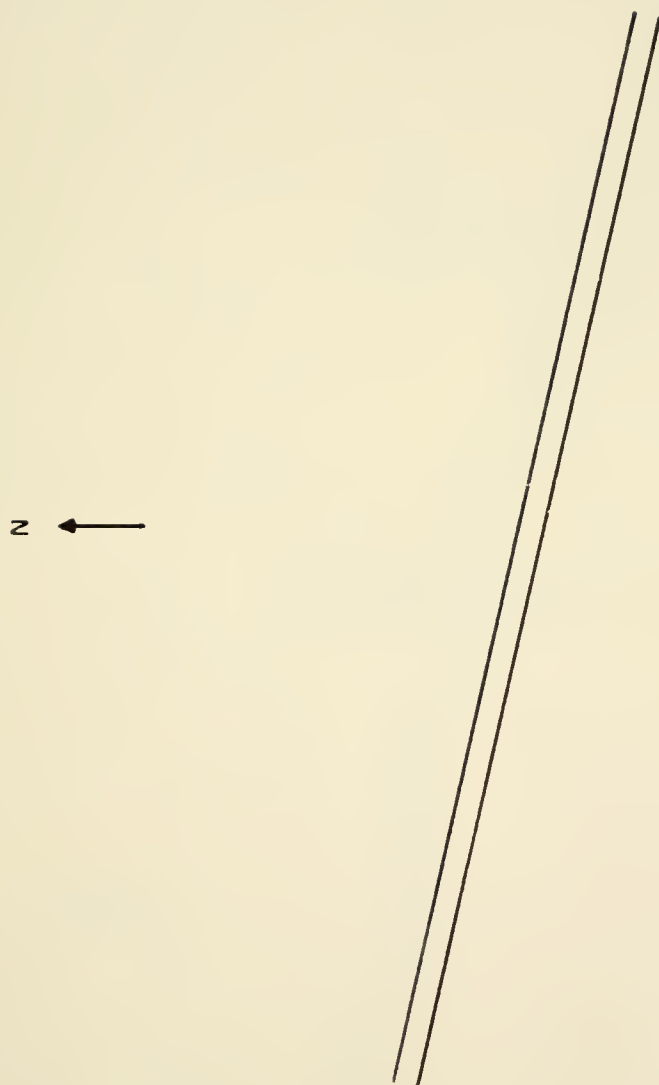
FIGURE 13   BYPASS , SECTION 6B

9TH ST. RD.

N
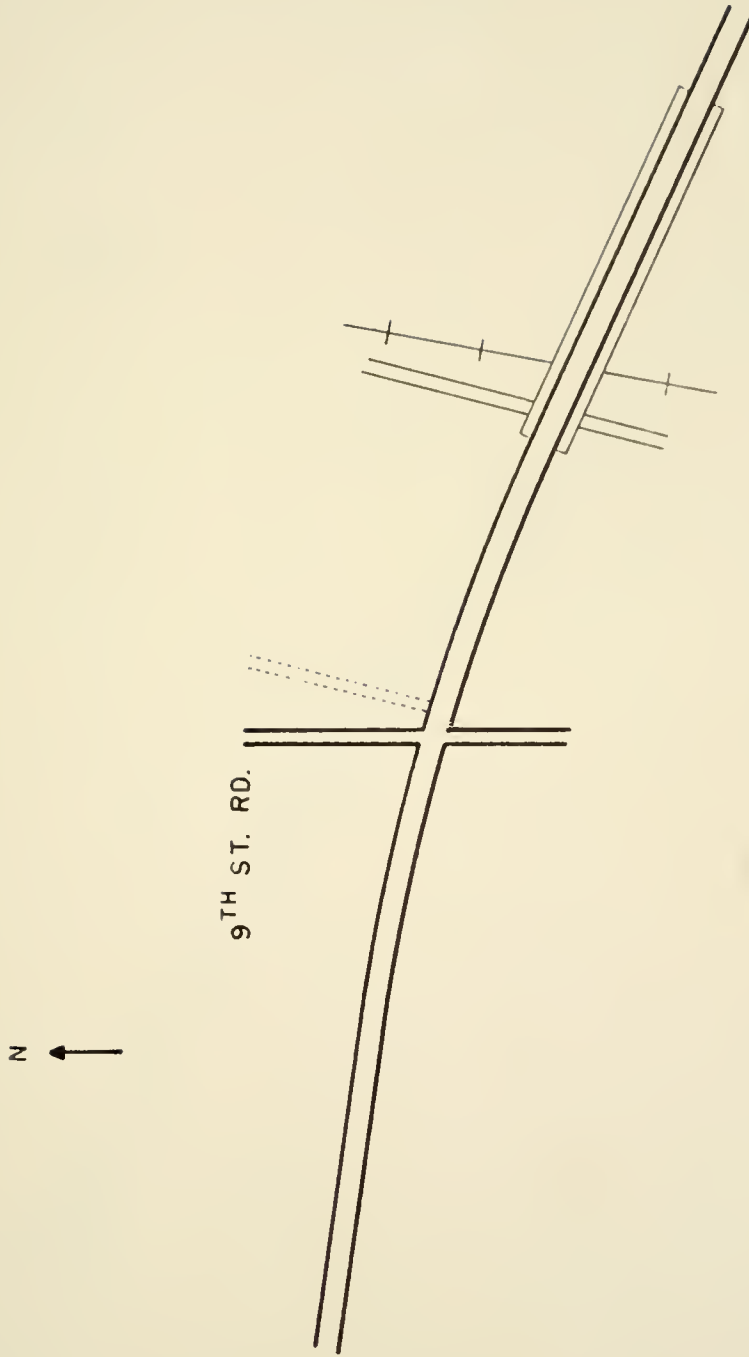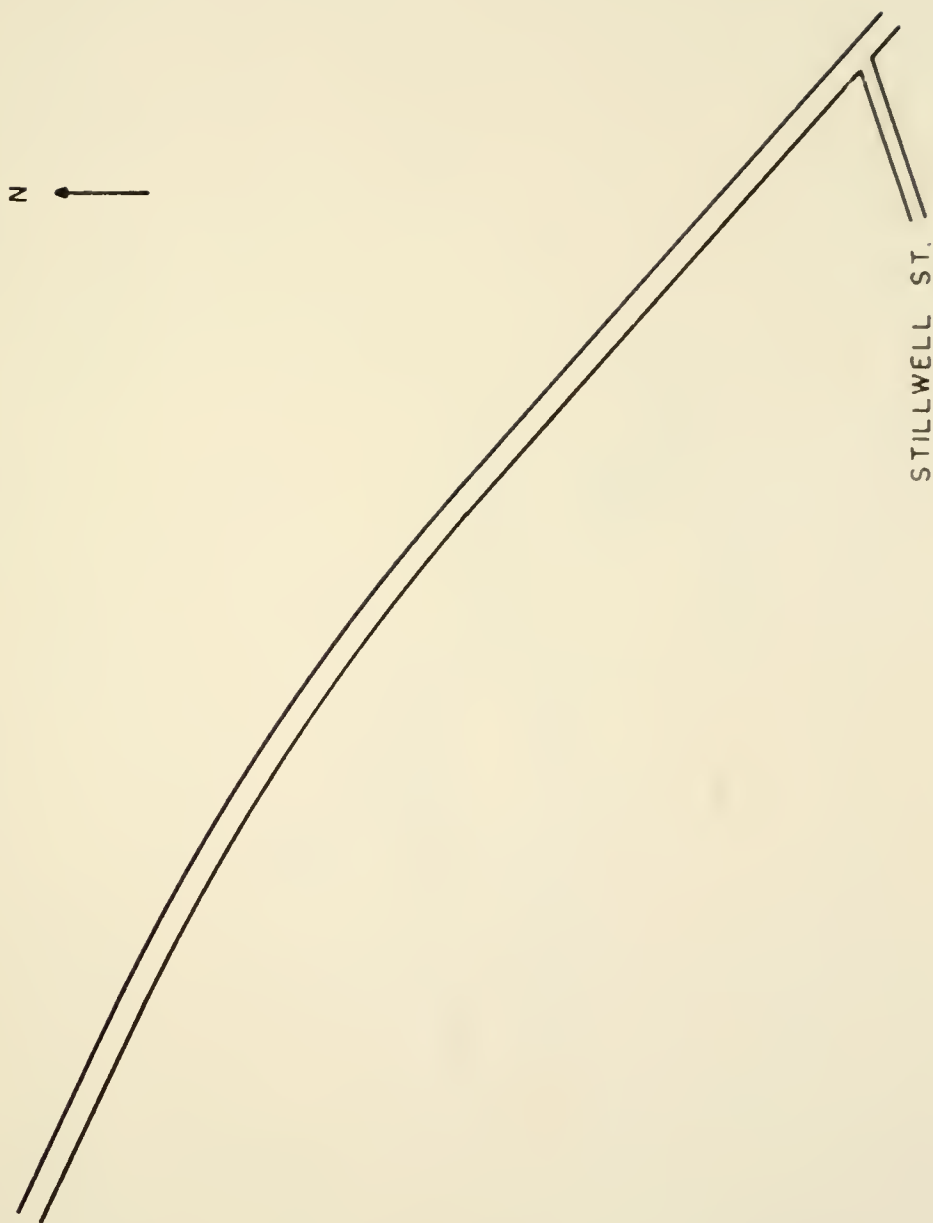
FIGURE 14   BYPASS, SECTION 7A

STILLWELL ST.

N

FIGURE 15   BYPASS, SECTION 7B

N

MONON AVE.

SCHUYLER AVE.

25TH ST.
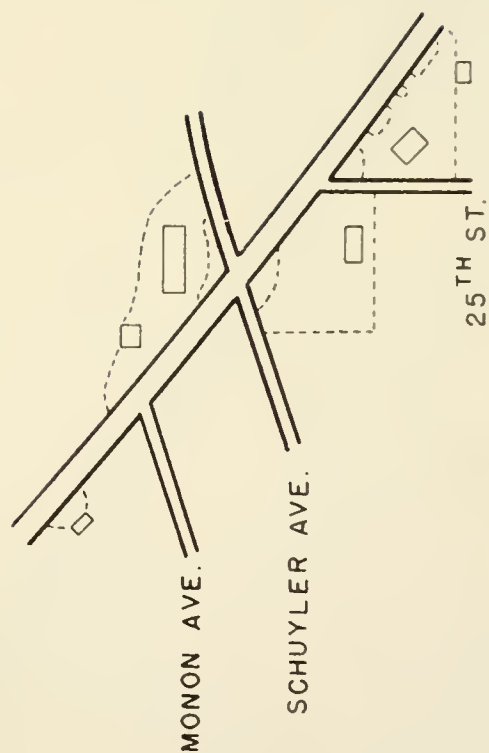
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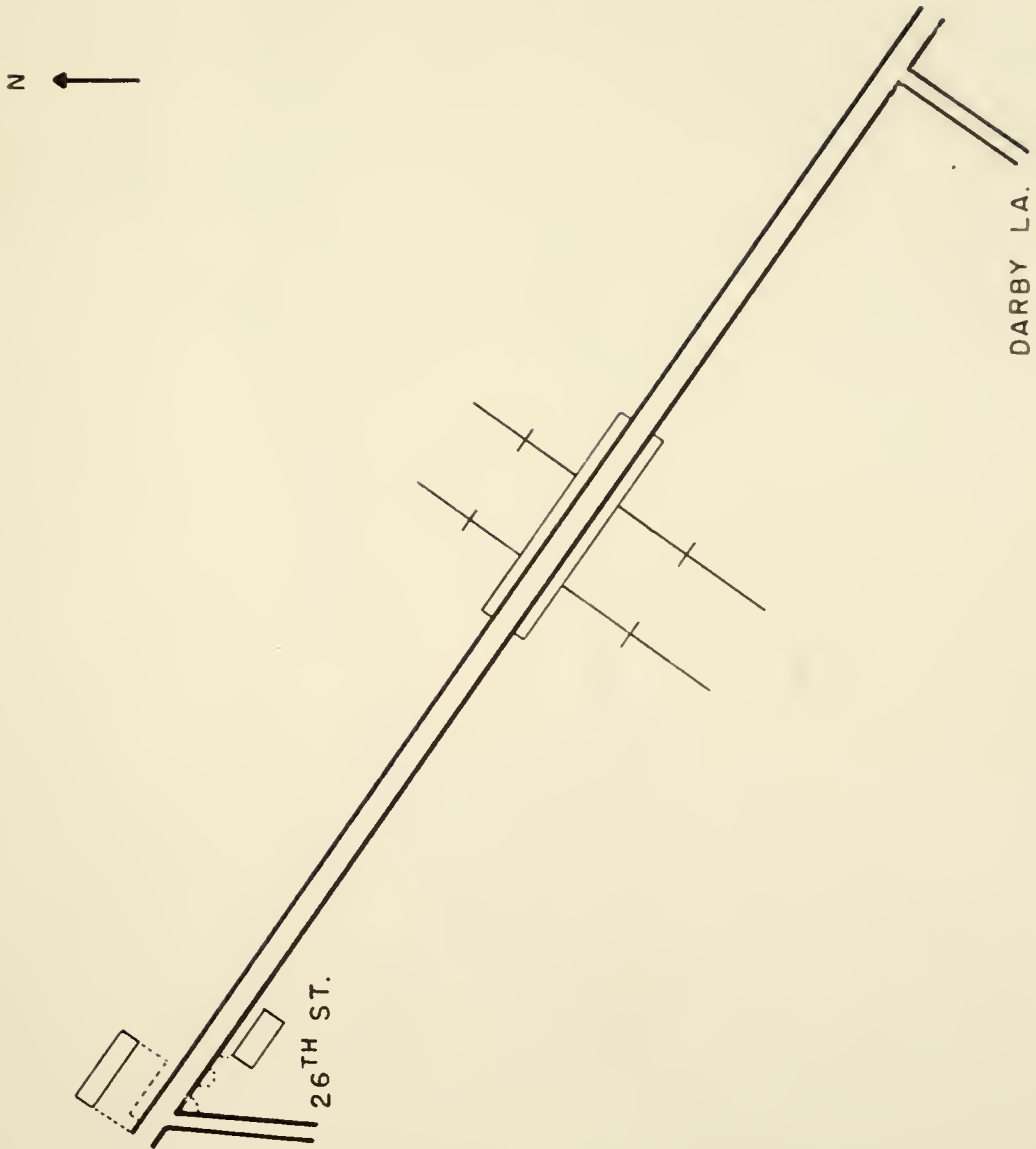
FIGURE 17   BYPASS, SECTION 9

BEECH LA.

UNDERWOOD ST.

N

FIGURE 18   BYPASS, SECTION 10

N

GREENBUSH ST.

FIGURE 19   BYPASS, SECTION II

FIGURE 20   BYPASS, SECTION 12

N

UNION ST.

FIGURE 21   BYPASS, SECTION 13

FIGURE 22   BYPASS, SECTION 14

SOUTH ST.

N

FIGURE 23   BYPASS, SECTION 15

FIGURE 24   BYPASS, SECTION 16A
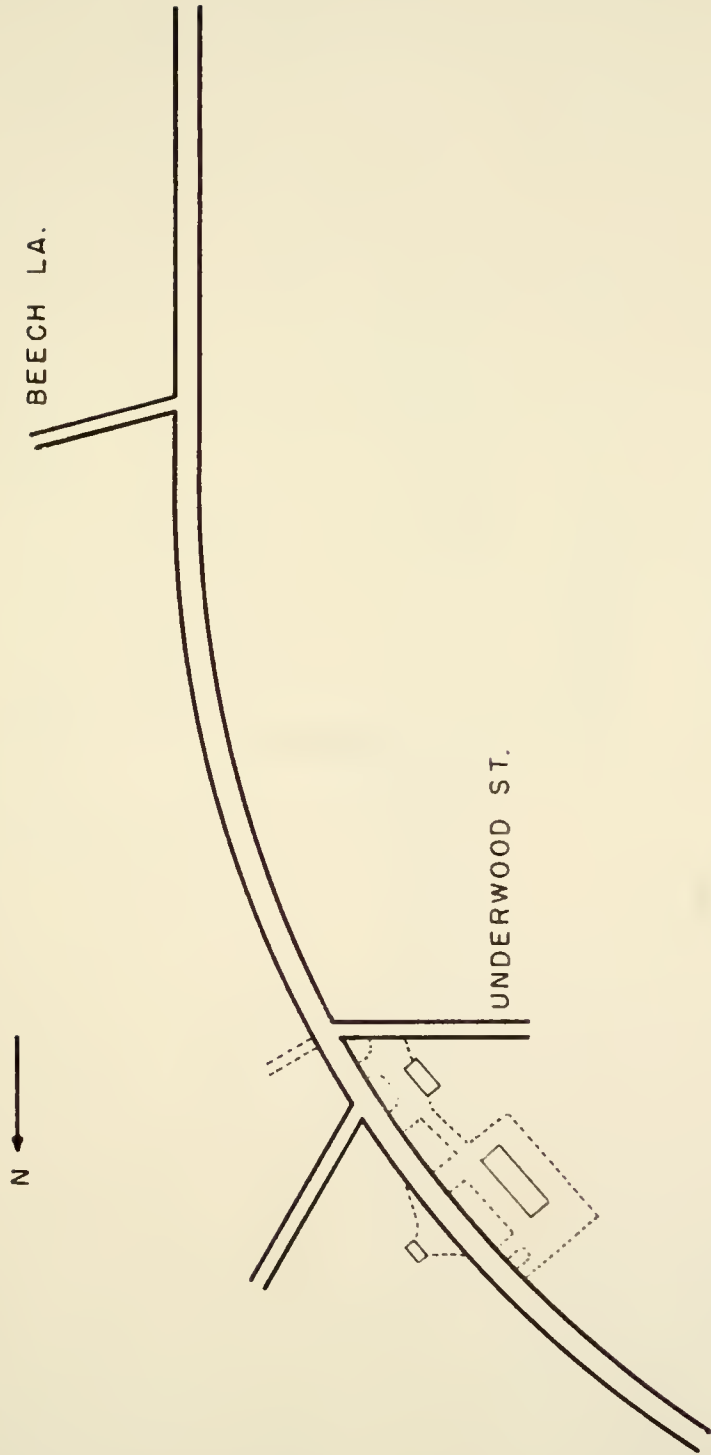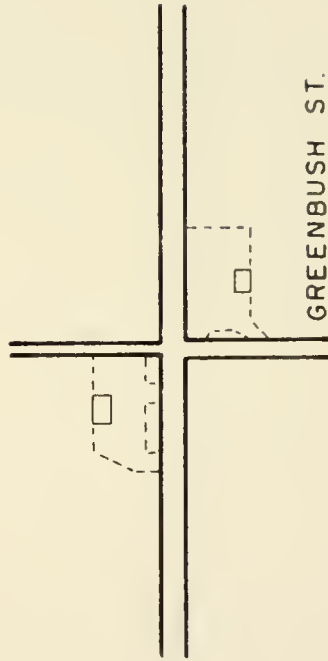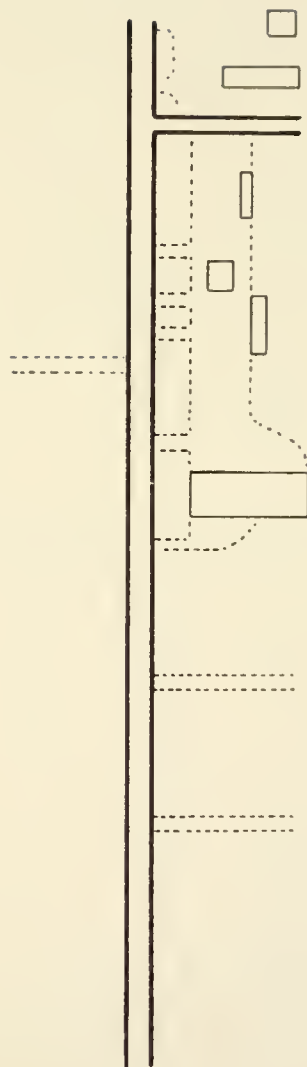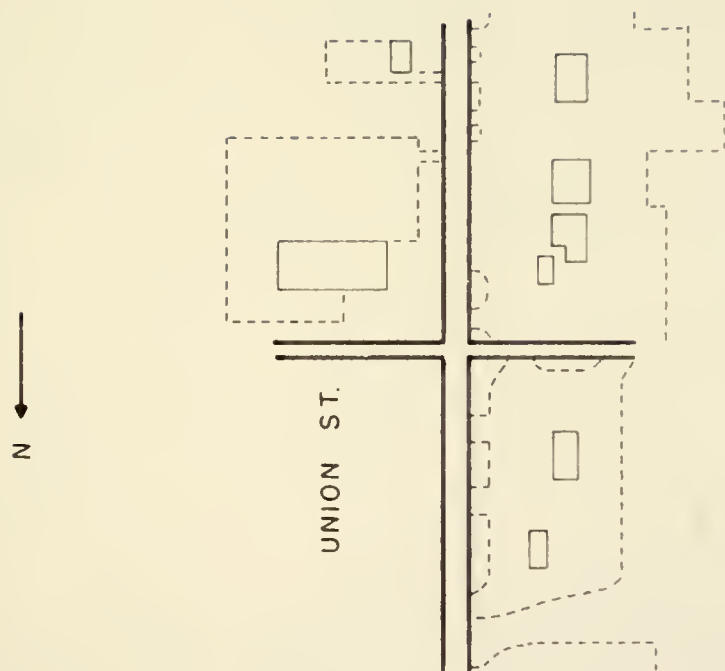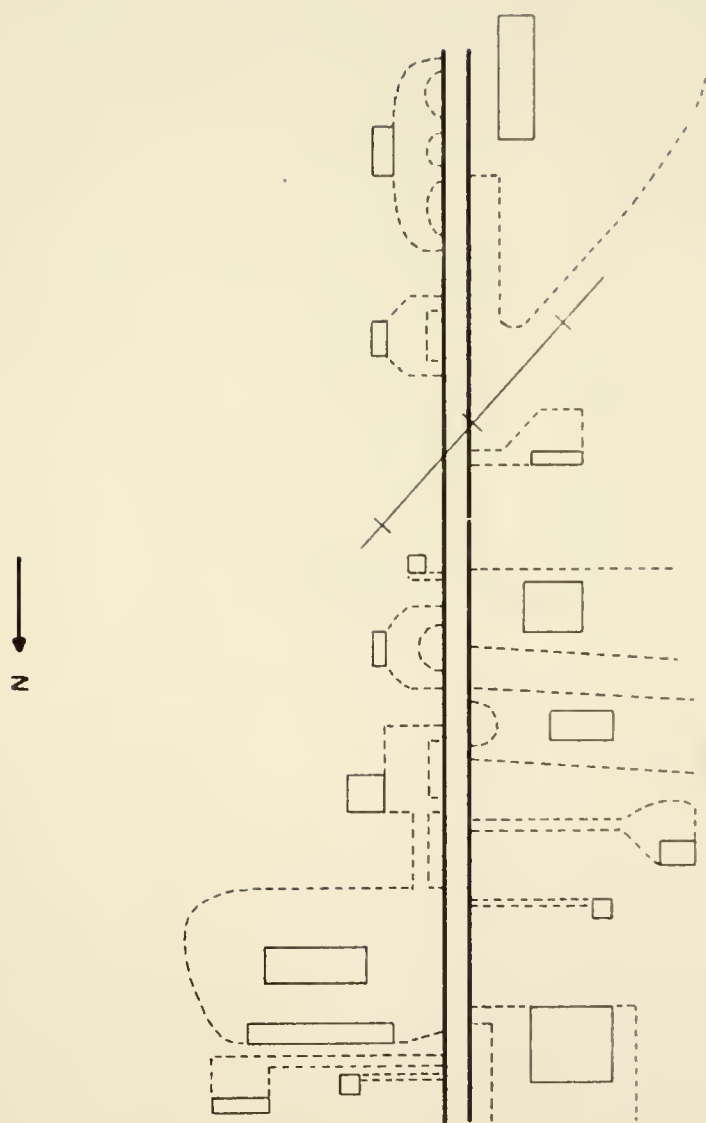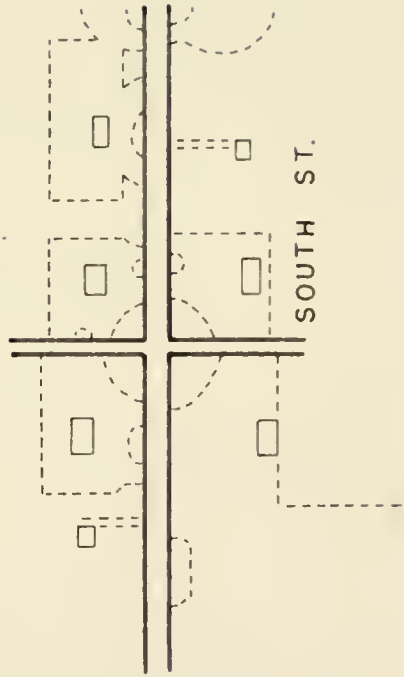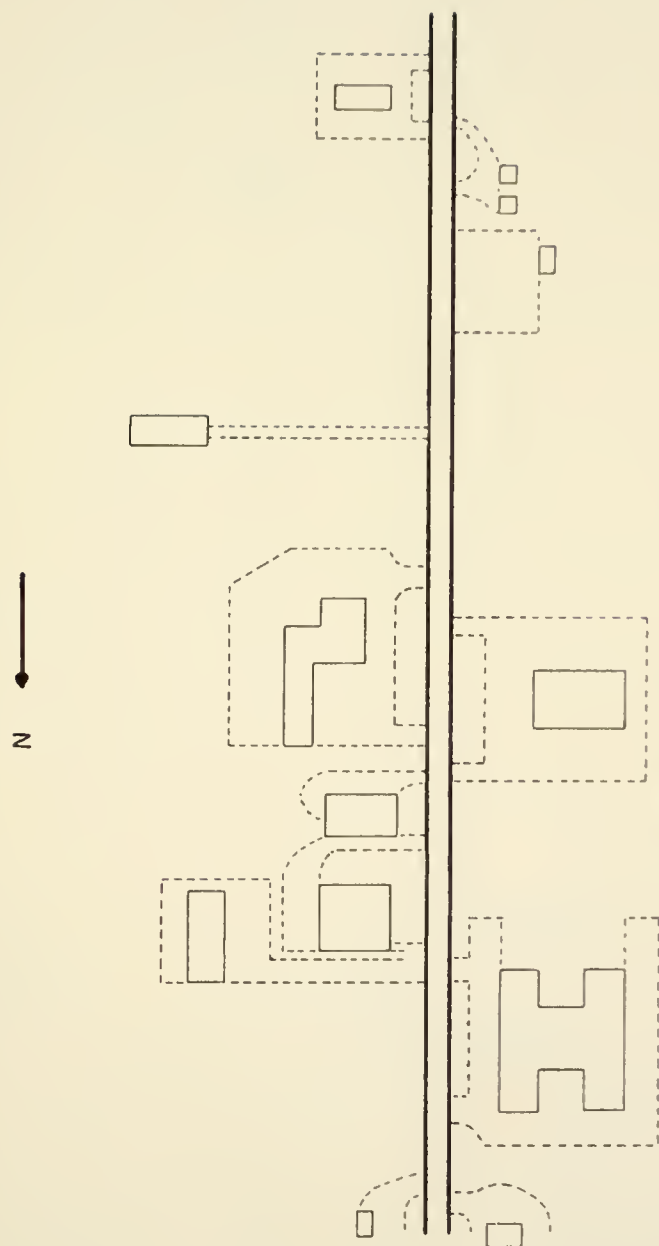
KOSSUTH ST.
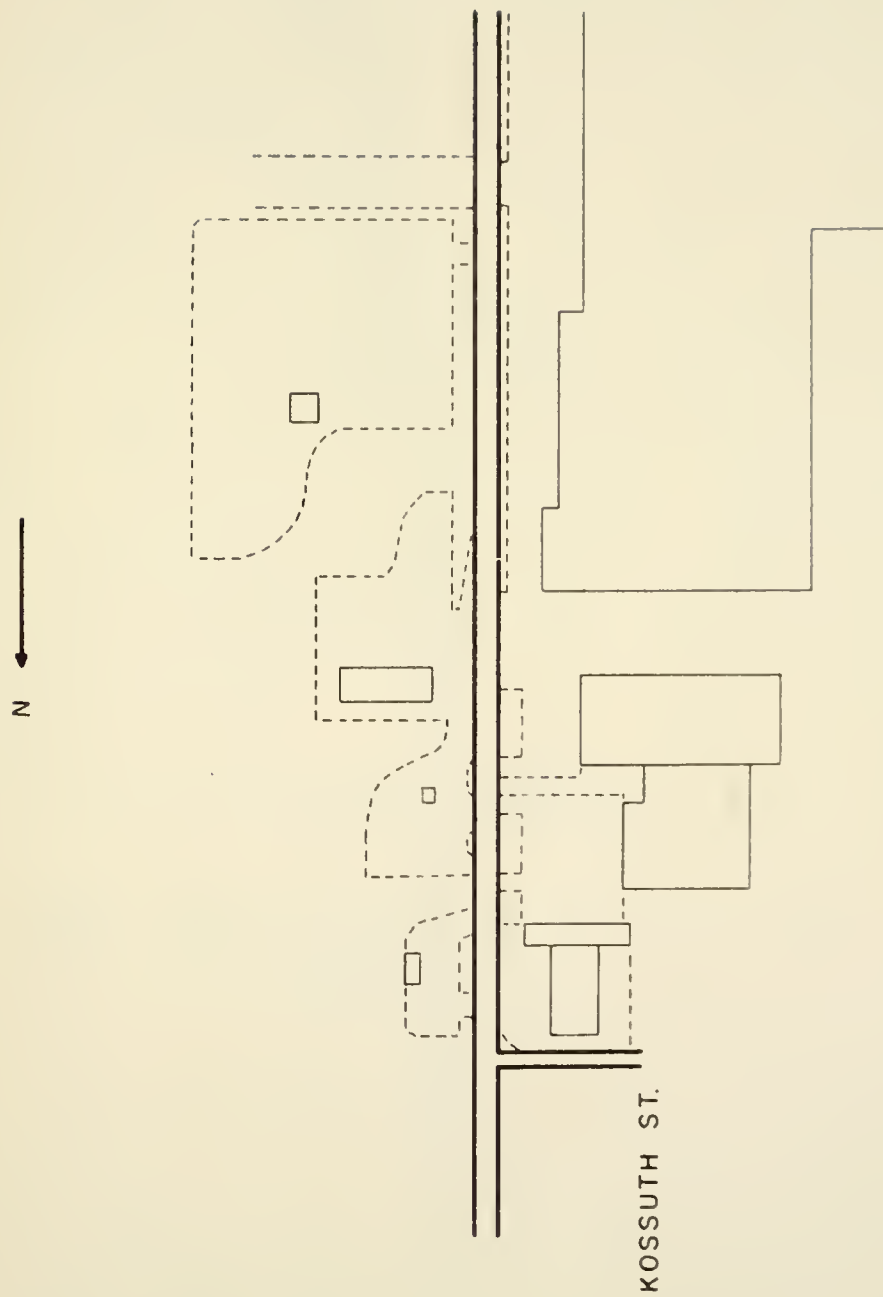
FIGURE 25   BYPASS, SECTION 16B
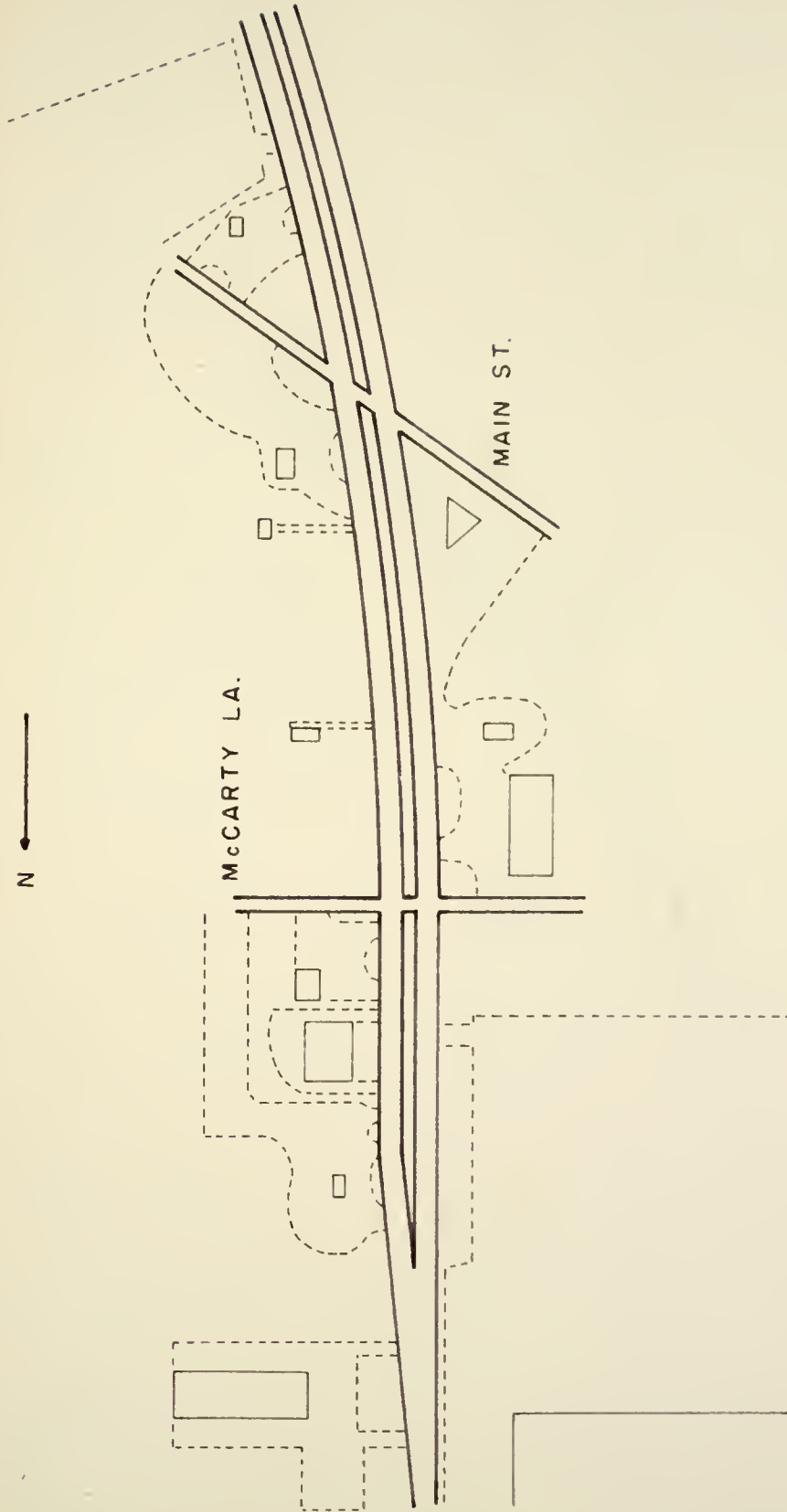
FIGURE 26   BYPASS, SECTION 17

N

TEAL RD.
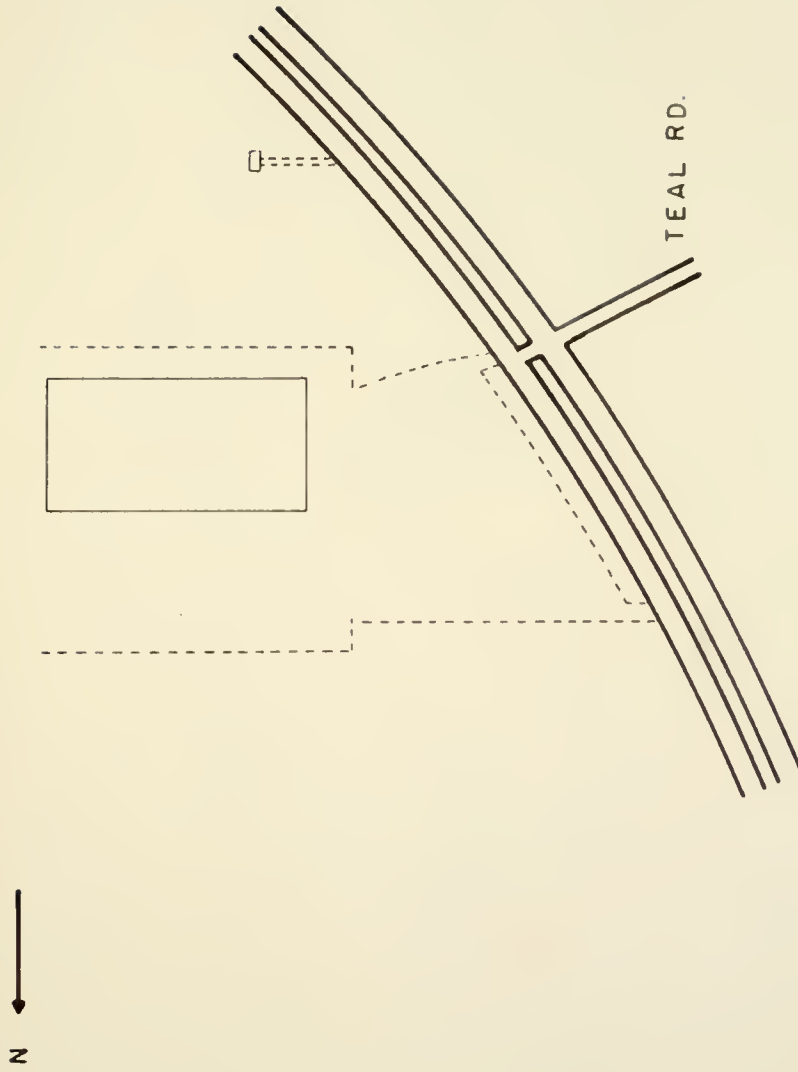
FIGURE 27   BYPASS , SECTION 18

APPENDIX B

SUMMARY DATA

TABLE 13

MEANS AND STANDARD DEVIATIONS OF STUDY VARIABLES,

UNINTERRUPTED FLOW

Variable	Mean	Standard Deviation
1	1.695	1.772
2	1.695	1.772
3	3.390	2.544
4	7.935	10.953
5	7.935	10.953
6	15.870	19.469
7	6.015	9.237
8	6.015	9.237
9	12.030	16.187
10	48.500	10.973
11	9.460	4.412
12	9.460	4.412
13	38.850	38.523
14	1.457	1.560
15	0.000	1.933
16	0.330	0.644
17	42.800	3.818
18	1683.500	624.620
19	762.000	259.616
20	1458.000	310.607
21	2.200	3.568
22	2.450	2.013
23	2.385	2.750
24	3.100	2.800
25	0.050	0.218
26	0.500	0.500
27	0.500	0.500
28	0.200	0.400
29	0.200	0.400
30	0.338	0.473
31	0.188	0.391
32	0.075	0.264
33	0.078	0.268
34	0.250	0.433
35	0.241	0.428
36	0.431	0.496
37	120.869	34.890
38	121.526	36.013
39	12.950	2.891
40	0.500	0.500
41	0.500	0.500
42	242.395	67.145
43	1.413	0.579
44	0.693	0.223
45	42.304	9.185

TABLE 14

CORRELATION OF TRAVEL SPEED WITH THE
OTHER VARIABLES, UNINTERRUPTED FLOW

Variable	Correlation Coefficient, Travel Speed
1	-0.169
2	-0.113
3	-0.196
4	-0.506
5	-0.468
6	-0.548
7	-0.512
8	-0.421
9	-0.532
10	+0.586
11	-0.340
12	-0.426
13	-0.074
14	+0.406
15	+0.028
16	+0.032
17	-0.103
18	+0.064
19	-0.365
20	+0.224
21	-0.005
22	-0.208
23	+0.158
24	-0.221
25	+0.255
26	-0.362
27	-0.429
28	-0.006
29	-0.081
30	+0.044
31	+0.067
32	-0.045
33	+0.077
34	+0.003
35	+0.063
36	-0.099
37	-0.527
38	-0.495
39	+0.087
40	-0.103
41	+0.103
42	-0.539
43	-0.062
44	-0.503

TABLE 15

CONTRIBUTIONS OF THE 13 PRINCIPAL FACTORS,

UNINTERRUPTED FLOW

(Unities in Diagonal of Correlation Matrix)

Factor	Eigenvalue	Percent of Total Variance	Cum. Percent of Total Variance
A	7.63	20.01	20.01
B	6.63	17.52	37.53
C	3.86	10.16	47.69
D	2.54	6.69	54.38
E	2.08	5.48	59.86
F	1.88	4.94	64.80
G	1.61	4.22	69.02
H	1.50	3.96	72.98
I	1.32	3.46	76.44
J	1.20	3.17	79.61
K	1.14	2.99	82.60
L	1.12	2.94	85.54
M	1.01	2.68	88.22

TABLE 16

MEANS AND STANDARD DEVIATIONS OF STUDY VARIABLES,

INTERRUPTED FLOW

Variable	Mean	Standard Deviation
46	0.200	0.400
47	0.100	0.300
48	0.100	0.300
49	482.600	371.428
50	377.000	218.327
51	0.401	1.558
52	-0.401	1.558
53	0.300	0.641
54	0.300	0.641
55	0.600	0.801
56	5.200	3.030
57	5.200	3.030
58	10.400	4.133
59	3.000	1.343
60	3.000	1.343
61	6.000	2.100
62	65.000	8.955
63	37.100	7.377
64	544.399	56.602
65	0.300	0.641
66	0.100	0.300
67	1.600	1.802
68	0.700	0.458
69	0.500	0.501
70	0.500	0.501
71	9.319	5.685
72	10.779	9.160
73	9.319	5.685
74	10.690	3.709
75	10.690	3.709
76	0.200	0.400
77	0.200	0.400
78	0.337	0.473
79	0.187	0.390
80	0.075	0.263
81	0.075	0.263
82	0.250	0.433
83	0.245	0.430
84	0.430	0.495
85	132.330	34.573
86	133.320	35.186
87	336.262	89.498
88	12.950	2.892
89	0.569	0.072
90	0.398	0.061
91	0.974	0.242
92	24.160	10.166
93	16.448	14.235

TABLE   17

CORRELATION OF TRAVEL SPEED AND DELAY WITH
THE OTHER VARIABLES, INTERRUPED FLOW

Variable	Correlation Coefficient	
	Travel Speed	Delay
46	+0.271	-0.175
47	+0.106	-0.110
48	-0.139	+0.177
49	-0.085	+0.177
50	+0.102	-0.047
51	-0.127	+0.122
52	-0.122	+0.126
53	+0.003	+0.065
54	+0.088	-0.017
55	+0.073	+0.038
56	-0.071	-0.007
57	-0.003	-0.046
58	-0.054	-0.039
59	+0.033	-0.053
60	+0.103	-0.111
61	+0.087	-0.105
62	-0.237	+0.157
63	-0.056	-0.028
64	+0.096	-0.144
65	+0.190	-0.157
66	-0.139	+0.177
67	-0.200	+0.188
68	+0.028	-0.021
69	-0.114	+0.135
70	+0.114	-0.135
71	+0.018	-0.053
72	-0.101	+0.106
73	-0.140	+0.135
74	+0.131	-0.164
75	-0.173	+0.192
76	+0.020	-0.035
77	-0.074	+0.097
78	+0.027	-0.048
79	+0.090	-0.071
80	-0.100	+0.097
81	+0.127	-0.084
82	+0.001	-0.012
83	+0.028	-0.037
84	-0.092	+0.088
85	-0.180	+0.091
86	-0.225	+0.149
87	-0.244	+0.139
88	+0.112	-0.102
89	+0.190	-0.229
90	+0.135	-0.112
91	-0.223	+0.147

TABLE 18

CONTRIBUTIONS OF THE 11 PRINCIPAL FACTORS,

INTERRUPTED FLOW

(Unities in Diagonal of Correlation Matrix)

Factor	Eigenvalue	Percent of Total Variance	Cum. Percent of Total Variance
N	7.61	18.57	18.57
O	6.09	14.85	33.42
P	5.81	14.17	47.59
Q	3.90	9.50	57.09
R	3.22	7.86	64.95
S	2.57	6.27	71.22
T	2.07	5.06	76.28
U	1.95	4.76	81.04
V	1.50	3.67	84.71
W	1.19	2.90	87.61
X	1.10	2.68	90.29